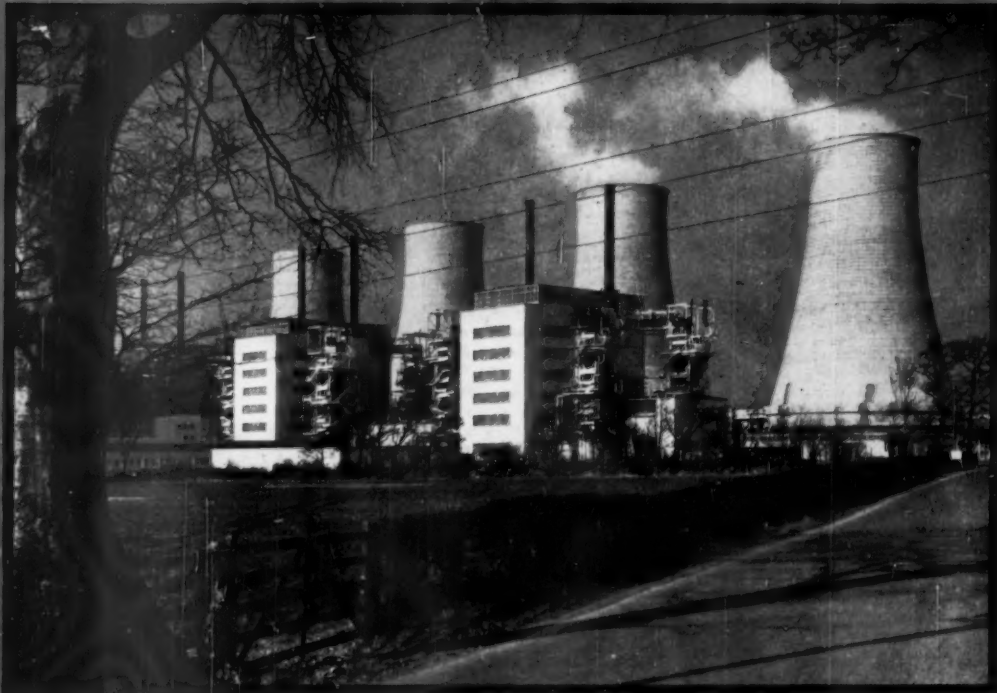


# COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

*August 1959*

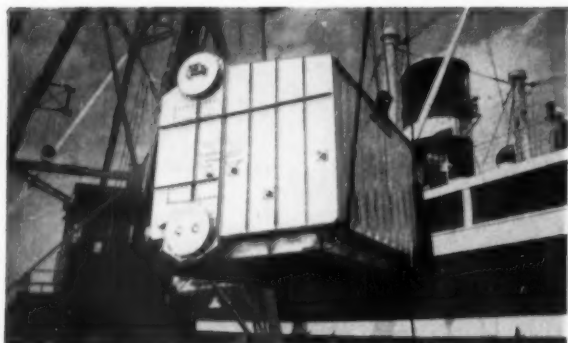


The Chapel Cross Station—Most recent addition to the nuclear generating facilities of the United Kingdom Atomic Energy Administration

**Fire Side Corrosion in Oil-Fired Boilers** ▶

**Steam Power Plant Clinic** ▶

**Boiler Tube Failures** ▶



▲ A C-E Package Boiler, Type VP, en route to Europe. This boiler type is available with capacities from 4,000 to 90,000 lb of steam per hr, with pressures to 700 psi and temperatures to 750 F in certain sizes. It is designed for oil or gas firing. Several hundred of these units are now in service.



▲ A shop-assembled Controlled Circulation Boiler, Type PCC, being prepared for shipment. This type unit is available with steam capacities from 80,000 to 120,000 lb per hr, and with pressures and temperatures to 1000 psi and 900 F. For special applications, designs are available to provide higher steam pressures and temperatures. Seven PCC Boilers are now in service.



▲ A shop-assembled C-E High-Temperature Water Boiler, Type HCC, being unloaded at a midwest manufacturing plant. It is one of two 12 million-Btu boilers used for plant heating. Available for capacities from 10 million to 300 million Btu, this unit type is shop-assembled in sizes up to 50 million Btu for oil or gas firing—up to 40 million Btu for coal firing. Currently, more than 50 HCC Boilers are in service or on order.

# NOW

## C-E offers LARGER SHOP-ASSEMBLED BOILERS

*Three service-proved designs with capacities to 120,000 lb per hr... pressures to 1000 psi... temperatures to 900 F*

The economies inherent in shop-assembled boilers can now be yours even if your steam requirements are as high as 120,000 lb per hr. The C-E line, consisting of three basic unit types, has been expanded to include pressures, temperatures and capacities well beyond normal package-type limits.

The standard, natural-circulation, **C-E Package Boiler—Type VP**—is now available with capacities to 90,000 lb per hr, and with pressures and temperatures to 700 psi and 750 F.

Where greater steaming capacity is required, or where higher pressures or temperatures are needed for industrial processing or power generation, the shop-assembled **C-E Controlled Circulation Boiler—Type PCC**—is available. It is designed for the 80,000-to-120,000-lb capacity range, with pressures to 1000 psi and temperatures to 900 F. For special applications, this unit is also available for considerably higher pressures and temperatures.

The **C-E High-Temperature Water Boiler—Type HCC**—is an ideal type for large space-heating and certain

process uses. It is also available in shop-assembled form for capacities to 50 million Btu per hr. It is designed for pressures to about 500 psi, and can provide water at 450 F or higher.

The new, high-capacity ranges of these shop-assembled units represent the logical evolution of familiar and successful designs that have been proved in service for quality, economy and performance.

Catalogs on any or all of these units available on request.

## COMBUSTION ENGINEERING



C-202A

Combustion Engineering Building  
200 Madison Avenue, New York 16, N. Y.  
Canada: Combustion Engineering-Superheater Ltd.

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

# COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 31

No. 2

August 1959

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ROBERT D. TAFT  
*Business Manager*

GLENN R. FRYLING  
*Associate Editor*

JOSEPH C. McCABE  
*Editor*

E. ROBERT LaCROSSE  
*Circulation Manager*

A. W. HINDENLANG  
*Associate Editor*

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BPA

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*any way you look at it...*

**YARWAY REMOTE LIQUID LEVEL INDICATOR  
GIVES BRIGHT, INSTANT, ACCURATE READINGS**

On its brilliant "wide vision" dial you can clearly read the level from any point in a 180° arc—and from a considerable distance.

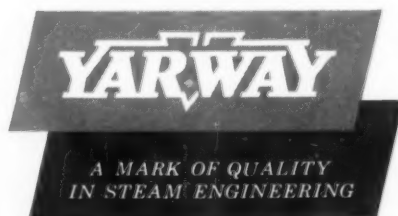
Remote readings of levels in boilers, feed water heaters and other heat exchangers are instant and accurate because indicator operating mechanism is actuated by the varying head of the liquid itself, yet the pointer mechanism is never under pressure.

Yarway Indicators may be arranged to operate remote Yarway Electronic Secondary Indicators or remote Hi-Lo Alarm Signals (lights or horns) located anywhere in the plant.

A record of nearly 13,000 successful installations speaks for itself.

For details on construction, operation, installation and typical hook-ups, write for Yarway Bulletin RI-1825.

**YARNALL-WARING COMPANY**  
100 Mermaid Ave., Philadelphia 18, Pa.  
BRANCH OFFICES IN PRINCIPAL CITIES





**GRAVER  
WATER  
CONDITIONING  
CO.**

Division of  
Union Tank Car Company

216 WEST 14TH STREET, NEW YORK

**Inter-Organization Correspondence**

**TO:** General Manager  
**FROM:** Technical Director  
**SUBJECT:** Review of Reactivator History

Approaching the 20th anniversary of the Reactivator we would like to summarize briefly its rise to the leading position among solids-contact water clarifiers and softeners. From the beginning, two basic elements were incorporated in the Reactivator design: positive sludge recirculation and mechanical sludge removal over the entire bottom area. Twenty years have confirmed the soundness of these original concepts.

By a constant effort to improve design performance, some important modifications have been made. (1) The method of inducing solids-contact was changed from air to impeller-pump to produce gentle and effective sludge recirculation. (2) The geometry of the machine was modified to get the best conditions for separation of solids from water. (3) Increased knowledge of sludge characteristics led to the redesigning of the sludge removal system.

As a result of these changes the Reactivator is able to provide: (1) solids-contact with the highest concentration of solids for the longest period of time; (2) an increase in throughput rate up to 2½-3 gpm/sq. ft., in certain cases; (3) more reliable and efficient mechanical sludge removal; (4) outstanding surge-proof characteristics.

Probably the most significant work in our program to improve the machine has been our very extensive field studies. We have had the opportunity to work with units from 8 to 125 ft. round and square on applications as widely divergent as...clarifying Arctic tundra lake water...softening and clarifying Mississippi and Colorado River waters...reducing color in Louisiana bayou water...treating hard, clear midwestern deep well supplies, and many more. The complete story of these applications is contained in our new Reactivator Bulletin WC-103C.

The sum total of our experience and knowledge has gone to make the present-day Reactivator the most versatile and reliable solids-contact unit on the market. It is gratifying to all of us to have participated in the development of such a machine.

ML/lz

*M.L.*

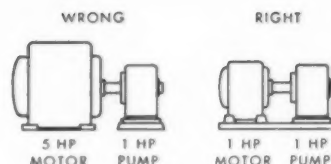
Technical Director

V.J.C.-  
This may be of  
interest to you  
H.T.S.

# Tips on evaluating Electrical

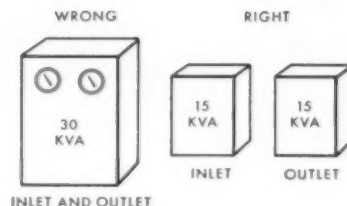
## Matched Electrical Sets

You wouldn't use a 5 h.p. motor to run a pump that required only one h.p. Similarly, electrical sets should be *matched* to the requirements of the specific job. Electrical sets should be sized according to gas conditions, dust conditions, and other operating characteristics, and in accord with manufacturers' past experience on similar installations. *Don't be misled by high KVA ratings on the electrical sets.* The precipitator will only absorb a certain amount of power and the sets should be sized accordingly. A large excess of installed power, which will never be used, means inefficient use of the equipment.



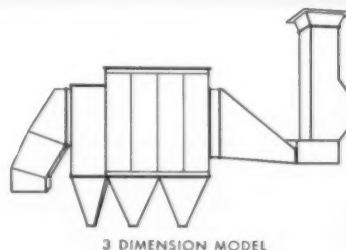
## Varied Electrical Conditions

Electrical conditions in a precipitator can vary widely at different parts of the precipitator. For instance, a high voltage, low current condition usually prevails at the inlet where the dust load is high, as compared to a lower voltage higher current condition at the outlet. Consequently, it is good design (and a necessity for high efficiency) to furnish several electrical sections in series, with energization from separate electrical sets so that each section can be adjusted to best suit the conditions.



## Gas Distribution

Remember that gas distribution, gas baffling, and provision against hopper sweeping all have a large influence on collection efficiency. The gas flow system should be analyzed as closely as possible, both in the precipitator and in the associated ductwork. If in doubt, have a three-dimensional gas flow study made. Two-dimensional gas flow studies are *not as accurate* and may lead to erroneous conclusions.

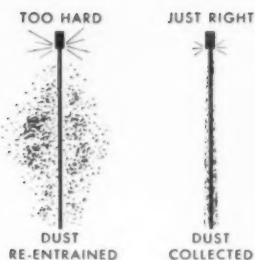


# RESEARCH

RESEARCH-COTTRELL, INC. Main Office and Plant: Bound Brook, New Jersey

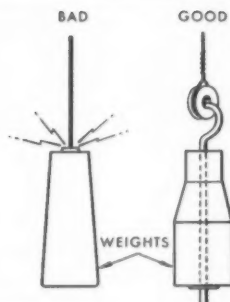
# Precipitators

Some helpful hints  
to aid in  
selecting a properly  
designed unit



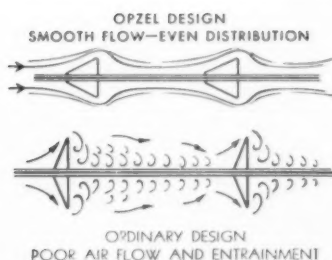
## Rapping Intensity

Rappers should have easy means to vary the intensity of the blow to suit variations in operating conditions. A pre-set intensity setting cannot possibly give proper rapping over the normal range of operation. If too soft, build-up will occur which will disturb electrical conditions. If too hard, there will be re-entrainment. Means of intensity adjustment are necessary to avoid drop-off of precipitator efficiency as conditions change.



## Corona Discharge

It is a relatively easy matter to obtain a corona discharge in an electrostatic precipitator. Many types of discharge electrodes have been used over the past forty years, including ribbons, squares, twisted squares, star shaped sections, coiled wires, wires with prongs and projections, most of which give entirely adequate corona conditions. Final choice then gets down to mechanical factors such as strength of wire, method of support to avoid stress points, and ease of handling. There are many claims made for various types of wires but after investigating and testing hundreds of different kinds, we find a straight round wire about .1" diameter to be best.

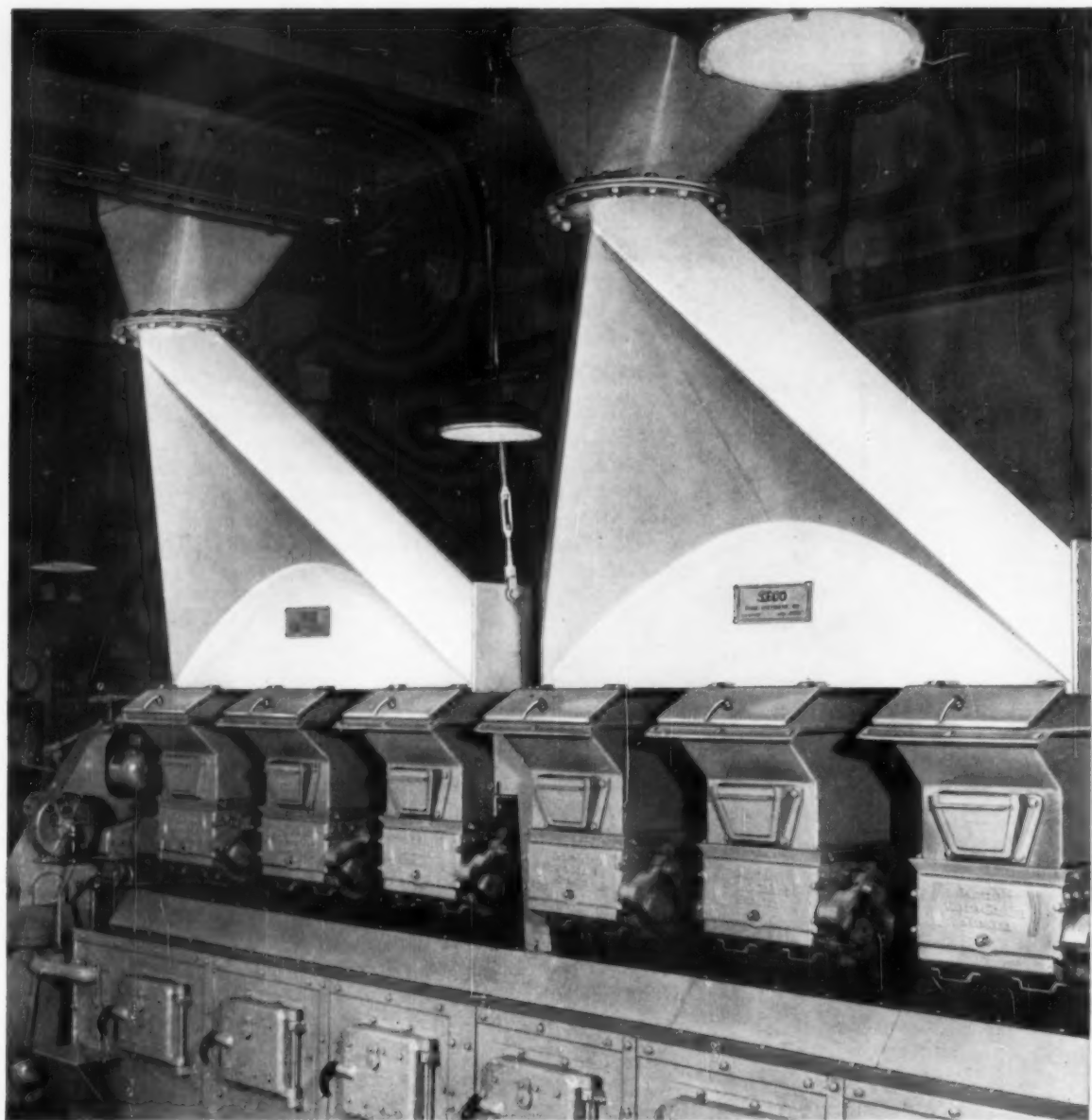


## Baffle Design

Careful attention to the design of baffles on the collecting plates is most important. Small amounts of reentrainment mean tremendous differences in over-all collection efficiencies. It is seen that the "quality" of the collecting surface is far more important than quantity — quantity (sq. ft. of surface or treatment time) in itself is not a criterion of performance.

# -COTTRELL

Representatives in all major cities of U.S. and Canada



**T**HERE'S no substitute for a S-E-Co. CONICAL Coal Distributor — it's truly non-segregating. You can rely on Stock Equipment Company's attention to details of design, layout, and fabrication, backed by years of specializing in this field. Be sure the distributor you buy will do the job it's supposed to do — help your stokers operate more efficiently and economically. Get a S-E-Co. CONICAL Non-Segregating Coal Distributor.

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and Underbunker Conveyors

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HIGH  
STEADY  
HEAT

?

## DAMPNEY COATINGS LIVE WITH IT!

True measure of a high-heat coating's worth is *continuous operation at rated temperature*. Yet many so-called "heat-resistant" coatings take only occasional peaks — fail rapidly in 'round-the-clock service.

Dampney coatings are rated always for day in, day out operation at maximum temperatures. Hold them to it, if schedules call for steady heat, or let them fluctuate to ambient and back. Either way, Dampney silicones and ceramics give you full protection — with plenty in reserve.

Most important, Dampney coatings are selected to meet specific conditions of operation, temperature and corrosive environment. Thus they establish a lasting foundation easily maintained and permanently ending time-consuming and costly surface preparation.

Repeat orders — from a typical customer, 26 in 12 months for enough material to protect 1,929,000 square feet of steel — is the best evidence we have that when industry wants honest high-temperature coatings, it remembers Dampney silicones and ceramics, identified by the two trade names, DAMPNEY and THUR-MA-LOX.

We suggest you do likewise when you want real protection — resistant to 1000°F., to atmospheric corrosion, and to weather exposure — for these industrial hot spots . . .

- |                               |                                  |
|-------------------------------|----------------------------------|
| stacks and breechings         | • turbine interiors              |
| steam lines                   | • precipitators                  |
| kilns                         | • coke ovens                     |
| forced and induced draft fans | • incinerators                   |
| heat-treating furnaces        | • pulverizers                    |
| autoclaves and retorts        | • blast and open hearth furnaces |

Remember, too, the first Dampney trade name and product, known and used today the world around, APEXIOR NUMBER 1 for boiler interiors. For all hot metal, wet or dry, the best protection available is made and marketed by

MAINTENANCE  
FOR METAL

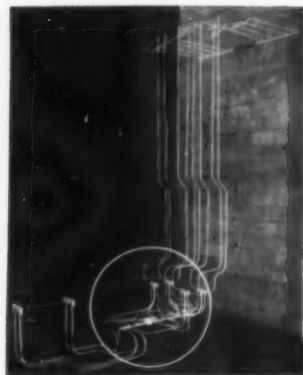
**THE DAMPNEY**  
COMPANY

HYDE PARK, BOSTON 36, MASSACHUSETTS

Coatings for all temperatures to high heat —  
all corrosive environments.

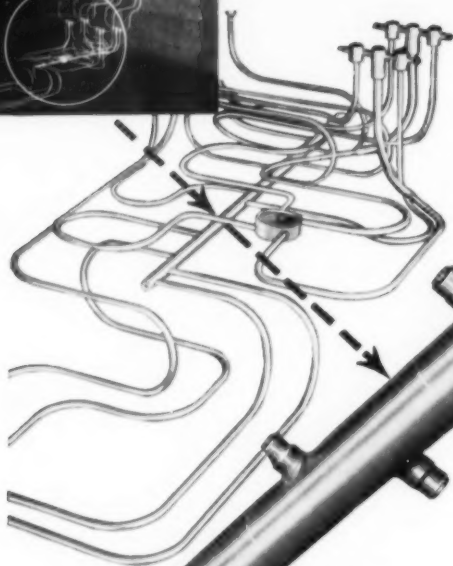
207





**PRETESTED and PREFABRICATED**  
for High-Temperature, High-Pressure Service by

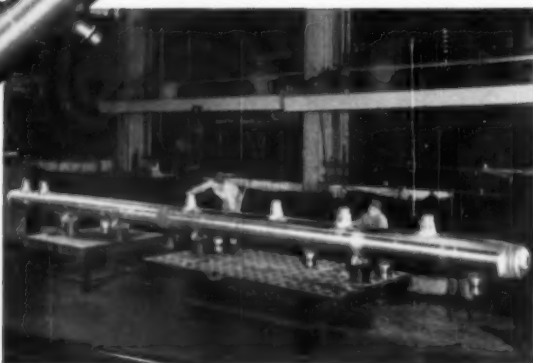
*Pittsburgh Piping*



**PART OF  
A COMPLETE  
PIPING  
SYSTEM**



**16,500 lb.  
Stainless Steel  
Main  
Steam Header**



Stress analysis of a model of power piping is an established procedure at Pittsburgh Piping. It is used to predict accurately the physical reactions of high-temperature, high-pressure piping in service.

The photograph at top left shows a model of main steam piping which is part of a complete system shop fabricated and field erected by Pittsburgh Piping. The enlarged section of the model indicates the relative size and location of the main steam header. This header, shown in the main photo, is fabricated of Stainless Steel Type 316. It weighs 16,500 lbs. and its wall thickness is 3".

Model testing and shop fabrication are two phases of Pittsburgh Piping service which covers every aspect of a piping job—from blueprint through erection. We are specialists—thoroughly experienced in the theoretical and practical aspects, as well as in the code and insurance requirements of high-temperature, high-pressure piping.

Promoting Progress **IN POWER AND PROCESS PIPING**

*Pittsburgh Piping*

**AND EQUIPMENT COMPANY**

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Atlanta.....Whitehead Building  
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Cleveland.....Public Square Building  
New Orleans.....P. O. Box 74  
.....Woolworth Building

PP-37

# 84,000 Hours of Reliable Viewing



## ... that is the Story of Dependability Behind Diamond's Television Camera Tube

***Nor is the Story Finished.  
The ORIGINAL TUBE,  
installed in 1949, is Still  
in DAILY OPERATION!***

At the Wood River Station of the Illinois Power Company, Diamond's "Utiliscope" Television system has provided 100% available viewing since 1949. In this job, dependability is all important! Only Diamond builds the tube which makes this availability possible.

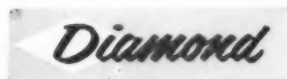
The operator, in the control room, sees the boiler water level at the drum by viewing the Diamond monitor mounted in the control panel. Water level

information is instantly and accurately available at all times from any viewing position in the control room.

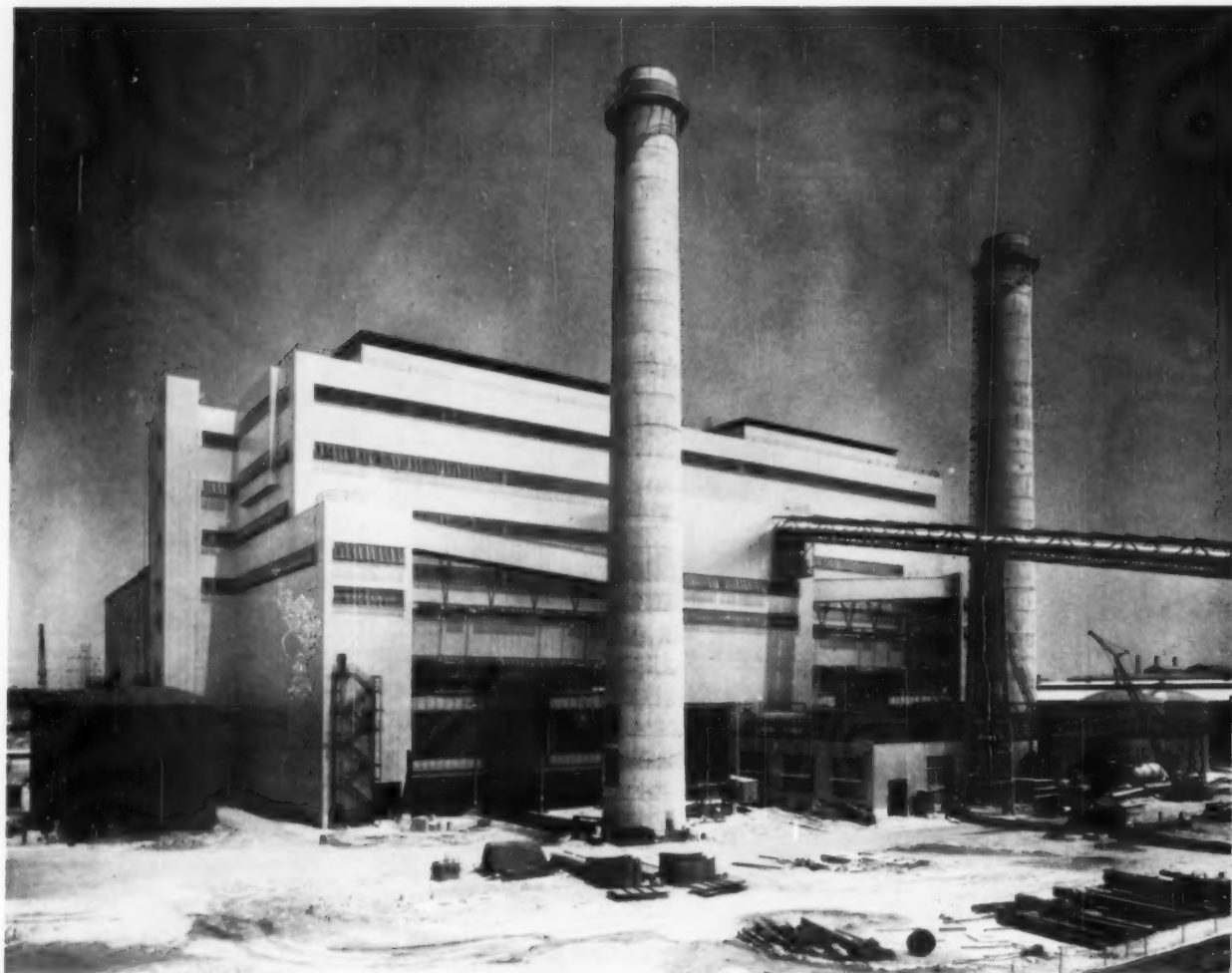
Routine maintenance is the only service required since installation. "Old Reliable" has a record of more than ten years of operation and is continuing to provide reliable service.

Such performance is not unusual for Diamond's "Utiliscope" equipment. This Heavy Duty Television is designed for industry. It is dependable, durable, resistant to time and difficult operating conditions. It is saving money and improving operation in power plants, steel mills, foundries, mines and a wide variety of manufacturing plants.

Write us for a non-obligating survey of your plant by our industrial television specialists. Electronics Division, Diamond Power Specialty Corporation, Lancaster, Ohio.



**DIAMOND POWER SPECIALTY CORP.**  
LANCASTER, OHIO *Diamond Specialty Limited, Windsor, Ontario*



Eddystone Station's Unit 1 has a capacity of 2,000,000 lb/hr at 5000 psig, and 1200°/1050°/1050°/F... uses C-E Sulzer Monotube Steam Generator.

## Vulcan Selective-Sequence system provides Eddystone Station with precision soot blowing

When Unit 1 of Philadelphia Electric's Eddystone Station goes into operation, a Vulcan Selective-Sequence system will accurately control all soot blowing.

Selective-Sequence systems were chosen for both units 1 and 2 at this super-critical station because they assure positive, dependable boiler cleaning... make the most efficient use of the blowing medium.

**Vulcan Controller saves time.** Without leaving the panel, the operator pushes a master button to place the system in sequential operation. He can see that each soot blower is operating in sequence for the proper inter-

val with adequate pressure. He can modify the sequence to improve cleaning or conserve the blowing medium without time-consuming wiring and piping changes.

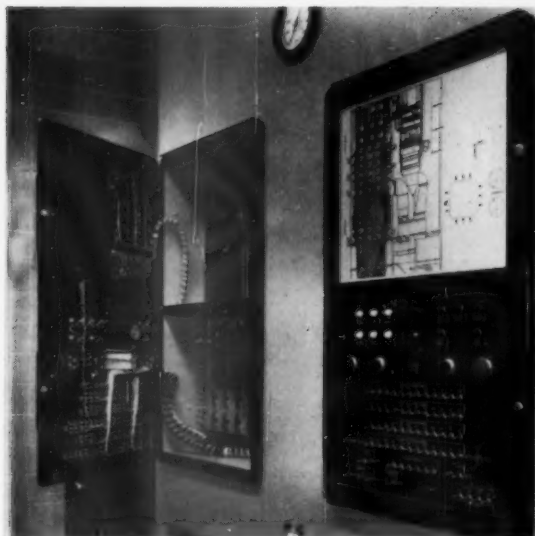
**Vulcan long retractables speed cleaning.** With dual-motor drive, Eddystone's T-30's clean uniformly; minimize the danger of tube cutting or erosion. Low rotating speed increases range and penetration of cleaning, decreases wear, eliminates whip, and permits proper cleaning with faster traversing speeds.

Half-tracts with 19-foot travel, wall deslagers, and air pre-heater controls are also used.



**COPES-VULCAN DIVISION**  
BLAW-KNOX COMPANY, ERIE 4, PA.



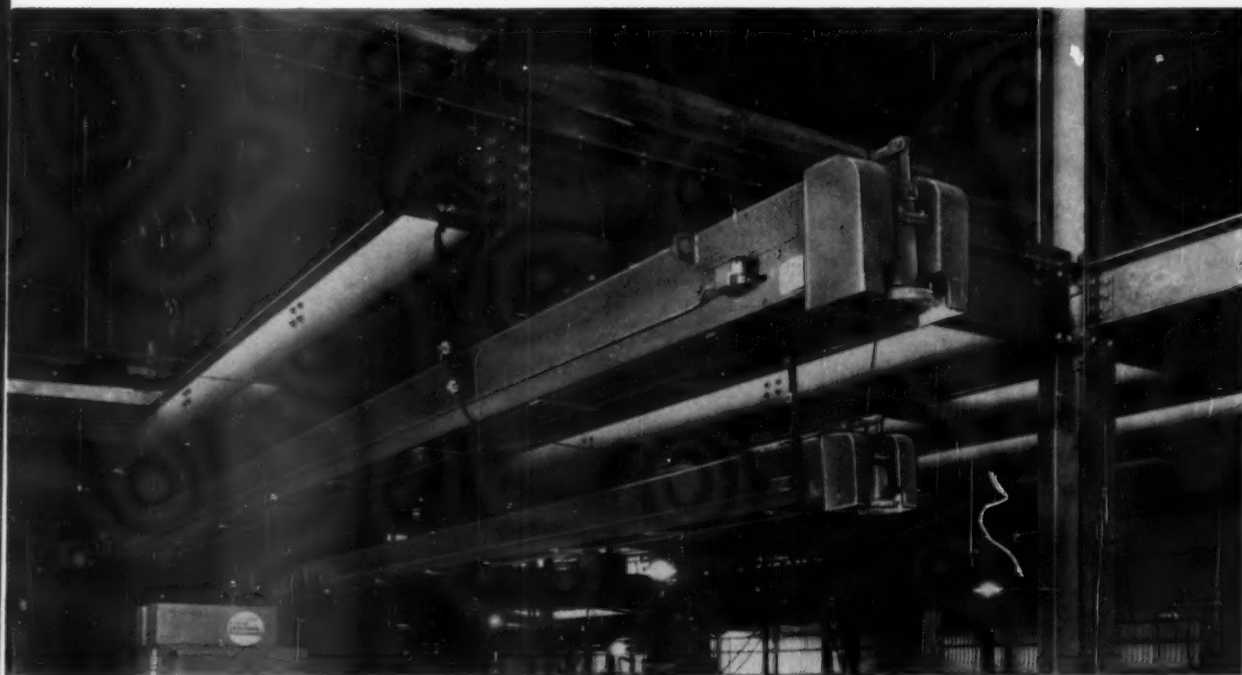


**Panel provides centralized control of soot blowing at Eddystone.** With the Vulcan SSC-120 Selective-Sequence controller, each blower can be operated four times during a schedule, or there can be four different schedules. The sequence can be varied by means of a jack board. Any soot blower can be operated at any point in the sequence by plugging one end of a patch cord into the blower jack, and the other end into the desired sequence jack. Write for Bulletin 1029.



**Wall deslagger conserves steam generated at Eddystone by three special package boilers.** High striking power of Vulcan RW-3E drives off gummy masses to assure high heat-transfer capacity, and uniform superheat and reheat temperature control. Dual motors are used: one speeds the nozzle to and from the blowing position, the other rotates it slowly for thorough cleaning. All parts are covered for protection, assuring long life with low maintenance. Write for Bulletin 1034.

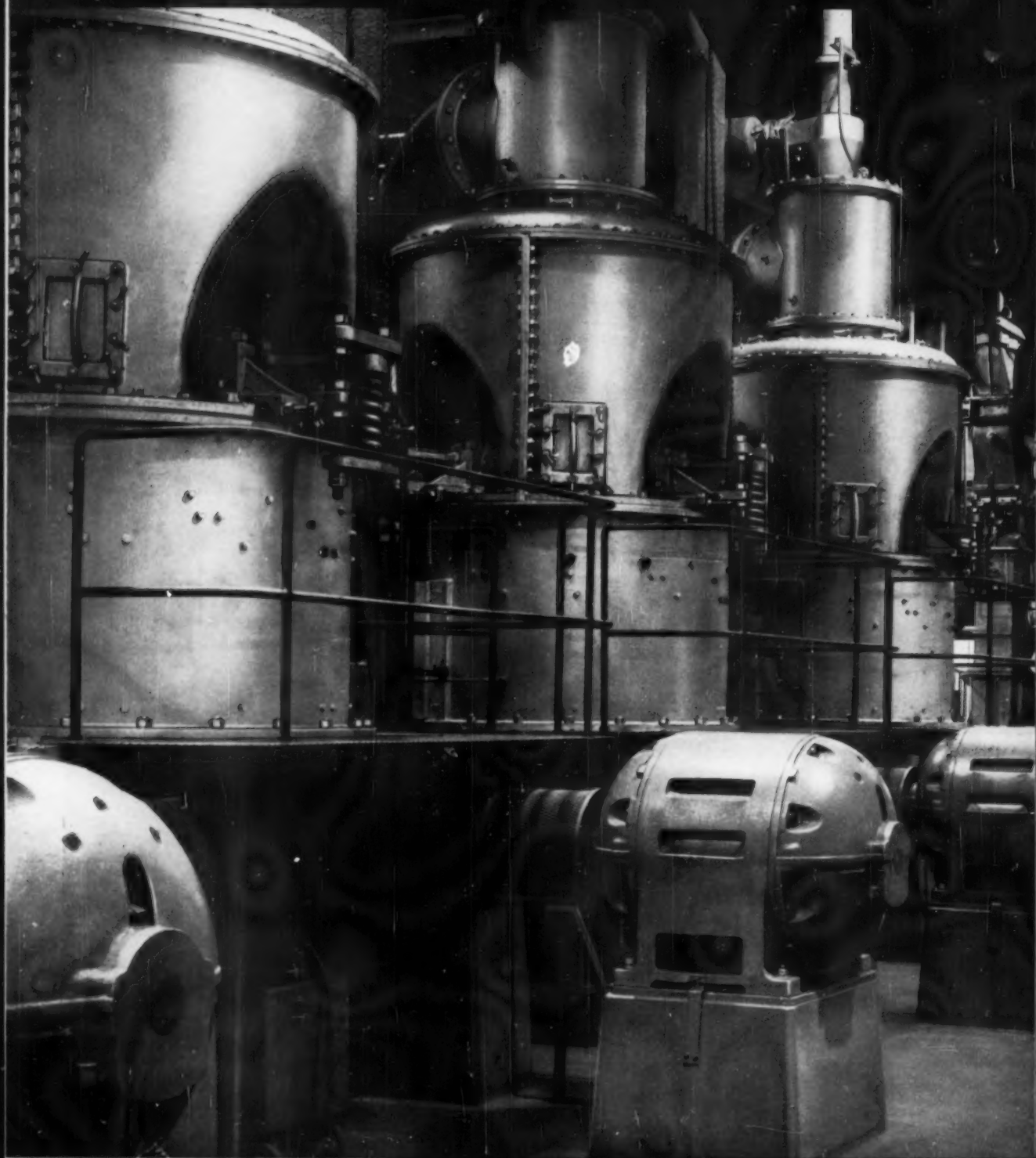
**Vulcan T-30's have 30- and 37-foot travels.** Motors are mounted at the boiler end to facilitate maintenance, yet away from heat of the boiler wall. Their placement avoids interferences. Write for Bulletin 1030.





# BOWL MILLS LIKE THESE

prepare the daily BTU diets of boilers







the world over

**C-E RAYMOND BOWL MILLS** pulverize lignite in Mallorca, Spain ... coke in Buenos Aires ... semi-bituminous coal in Limburg, Holland ... bituminous in Tanagawa, Japan ... furfural residue in Tennessee ... and petroleum coke in Indiana. But their biggest field of application, by far, is pulverizing various kinds of coal in hundreds of American utility plants from coast to coast. In all, they feed the boilers of the world with some 37,000 tons of fuel each hour — boilers with an aggregate steam generating capacity of about ...

**400,000,000 lb. per hr.**

There are eight big reasons why the C-E Raymond Bowl Mill is so popular — reasons that are important to you if pulverized fuel is part of your plant picture. They are ...

- 1. Handles High Moisture Fuels** — High moisture fuels are handled without difficulty because the Bowl Mill premixes raw coal with the dried product in an atmosphere up to 700 F air. Even lignite with 50% moisture is thoroughly dried.
- 2. Low Power Consumption** — Rapid flow of material through the mill, prompt removal of fine coal, fast drying and relatively low weight of grinding elements all combine to assure minimum power consumption.
- 3. Continuous Service** — The Bowl Mill provides continuous service for long periods because there is no metal-to-metal contact between rings and rolls and wear is minimized. Logs showing 20,000 hours of continuous operation are not uncommon.
- 4. Low Maintenance** — Maintenance is required less frequently because the Bowl Mill stays in service for longer periods. When replacement of parts is necessary, outage time is minimized because of the ease with which the machine can be taken apart and reassembled.
- 5. Fineness Control** — Changes in fineness control can be made while the Bowl Mill is operating because the necessary adjustments are made from the outside. The mill need not be stopped.
- 6. Automatic Grinding Adjustment** — Grinding pressure is automatically adjusted to suit fuel characteristics because the Bowl Mill uses spring-loaded journals which instantaneously compensate for variations in coal grindability.
- 7. Infrequent Lubrication** — Only infrequent lubrication is required with the Bowl Mill. When required, it can be done from outside the mill without taking it out of service.
- 8. Vibrationless-Quiet** — The Bowl Mill's grinding rollers make no metal-to-metal contact with the grinding ring, assuring quiet, vibrationless operation.

Whether you are considering pulverizers for your present plant expansion program or for future requirements, we suggest you investigate the advantages of the Bowl Mill as outlined above and described more fully in our Catalog PC-8.

## COMBUSTION ENGINEERING

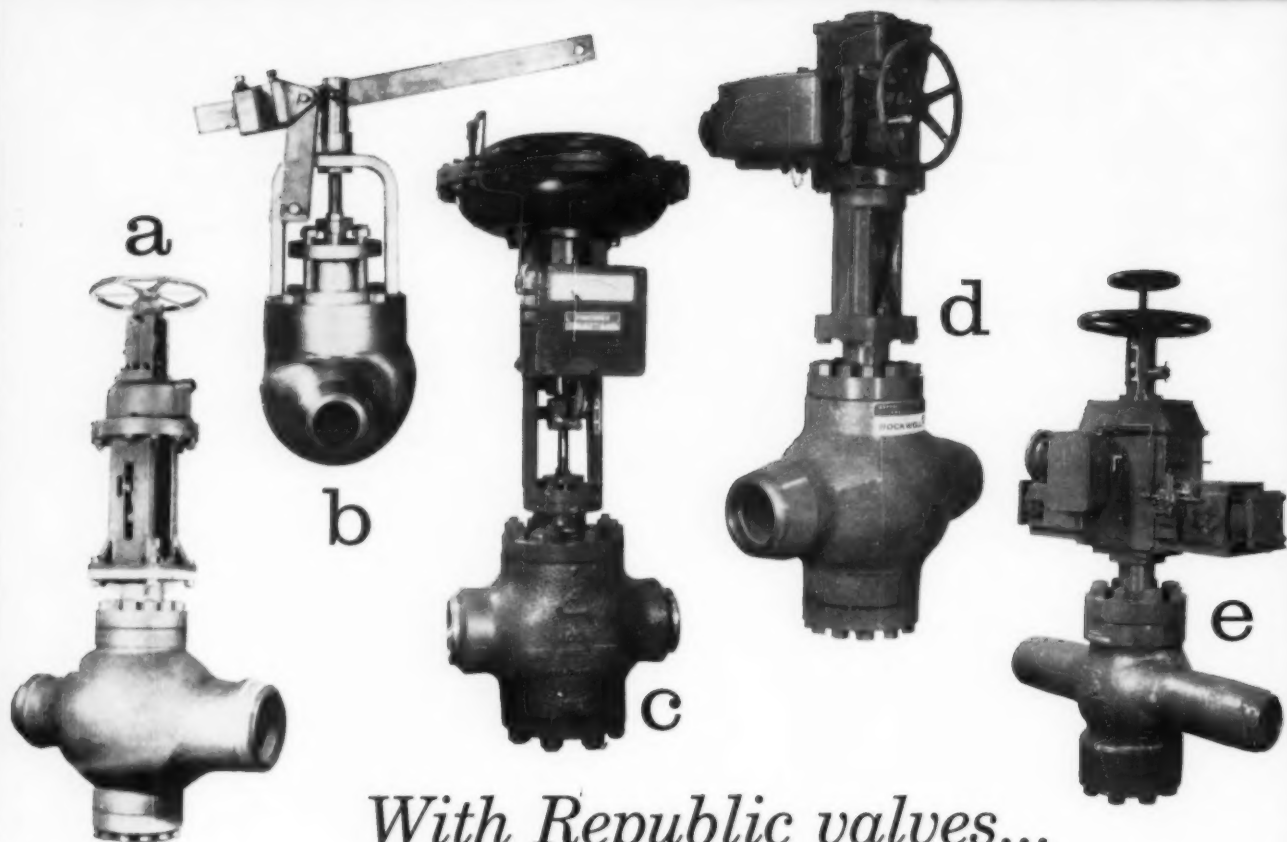


C-229

200 Madison Avenue, New York 16, N. Y.

Combustion Engineering Building

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT;  
NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING  
SYSTEMS; PRESSURE VESSELS; SOIL PIPE



*With Republic valves...*  
**You get longer life, less maintenance**

For over 35 years Republic valve developments have paced the changing demands for more sturdy valves by the most progressive utilities and industries. For such services as pump recirculation control, feedwater regulation, steam pressure reducing and high pressure water control, Republic valves have established a reputation for durability, long life and trouble-free performance.

**Superior valve design**—Republic research into the causes of valve noise and vibration, and also the wear resisting and galling properties of materials has resulted in a modern line of Republic valves of advanced design. Republic valve contours are designed to produce not only the desired regulating characteristics but also to reduce erosion damage and noise as well. Extra large guide bushings, extra deep stuffing boxes, solid plug inner valve construction, plus precise manufacture and long-life materials make Republic regulating valves perform better, last longer, with less maintenance.

**Wide selection of valves and features**—Rockwell-built Republic regulating valves shown on this

page are representative of the complete Republic line:

- a. Cylinder operated valve
- b. Lever operated valve
- c. Diaphragm operated valve
- d. Motor operated valve
- e. Toggle head operated valve
- f. Diaphragm operated angle valve

And, for many special applications, such Republic accessories as pneumatic and electric valve positioners for hysteresis-free control, and a complete line of controllers are available.

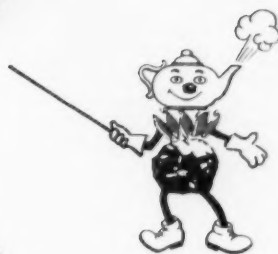
Whatever your regulating valve problem, let Republic engineers put their years of application experience to work for you. For additional information, see your Republic representative, or write to Republic Flow Meters Company, 2240 Diversey Parkway, Chicago 47, Illinois.



# VALLEY CAMP

## Quality Coals

**Engineered  
for  
Better Burning**



Our combustion engineering service is available  
to help you solve your steam cost problems.



## THE VALLEY CAMP COAL COMPANY

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## Quick Opening Bayer Soot Blower Valves Assure

- 100% cleaning efficiency
- minimum steam consumption
- superior high temperature resistance

The Bayer Balanced Valved Soot Blower is a single-chain operated design that assures precise sequential operation of the valve and element. *Only* after the start of full steam flow does element rotation commence—a feature which provides positive and efficient cleaning over the entire arc, . . . without wasting steam.

The Bayer Soot Blower is simply operated by a pull on the chain which opens the cam-actuated valve. Continued pulling of the chain slowly rotates the element through its cleaning arc, at the end of which the valve automatically closes.

For severe high temperature locations, "super service" elements of Bayer-developed "Chronilloy" are available. Of superior strength, wrap-resistance, and stability, these elements resist the oxidation and chemical action caused by very high temperature gases.

In over fifty years of continuous specialized service, the Bayer company has equipped more than 35,000 boilers with dependable soot blowers. Engineered for long life and low maintenance, Bayer products assure economical and trouble-free operation.

### ADVANTAGES OF THE BAYER BALANCED VALVED SOOT BLOWER

- single chain operation
- individual elements adjustable for high pressure service by orifice plate valve
- full steam pressure over entire cleaning arc
- selected gear ratios for optimum rate of element rotation
- minimum pressure drop through valve body
- machined air seal with spring loaded seat
- complete vacuum breaker protection
- precision swivel tube alignment lessens stuffing box packing needs
- load carried on ring type thrust bearings

**For further information contact the Bayer representative nearest you.  
He is an experienced engineer, qualified to service Bayer Soot Blowers.**

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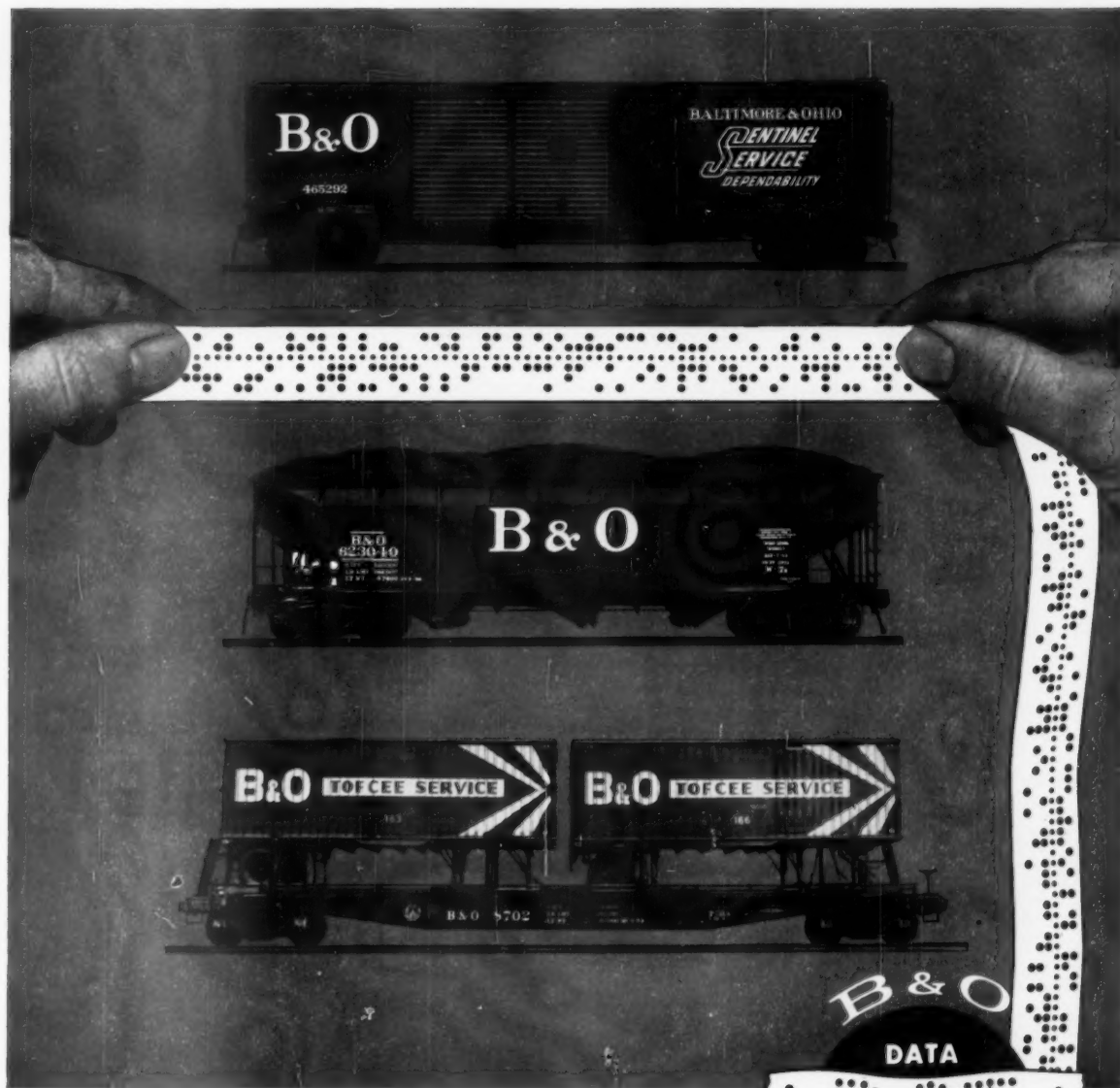
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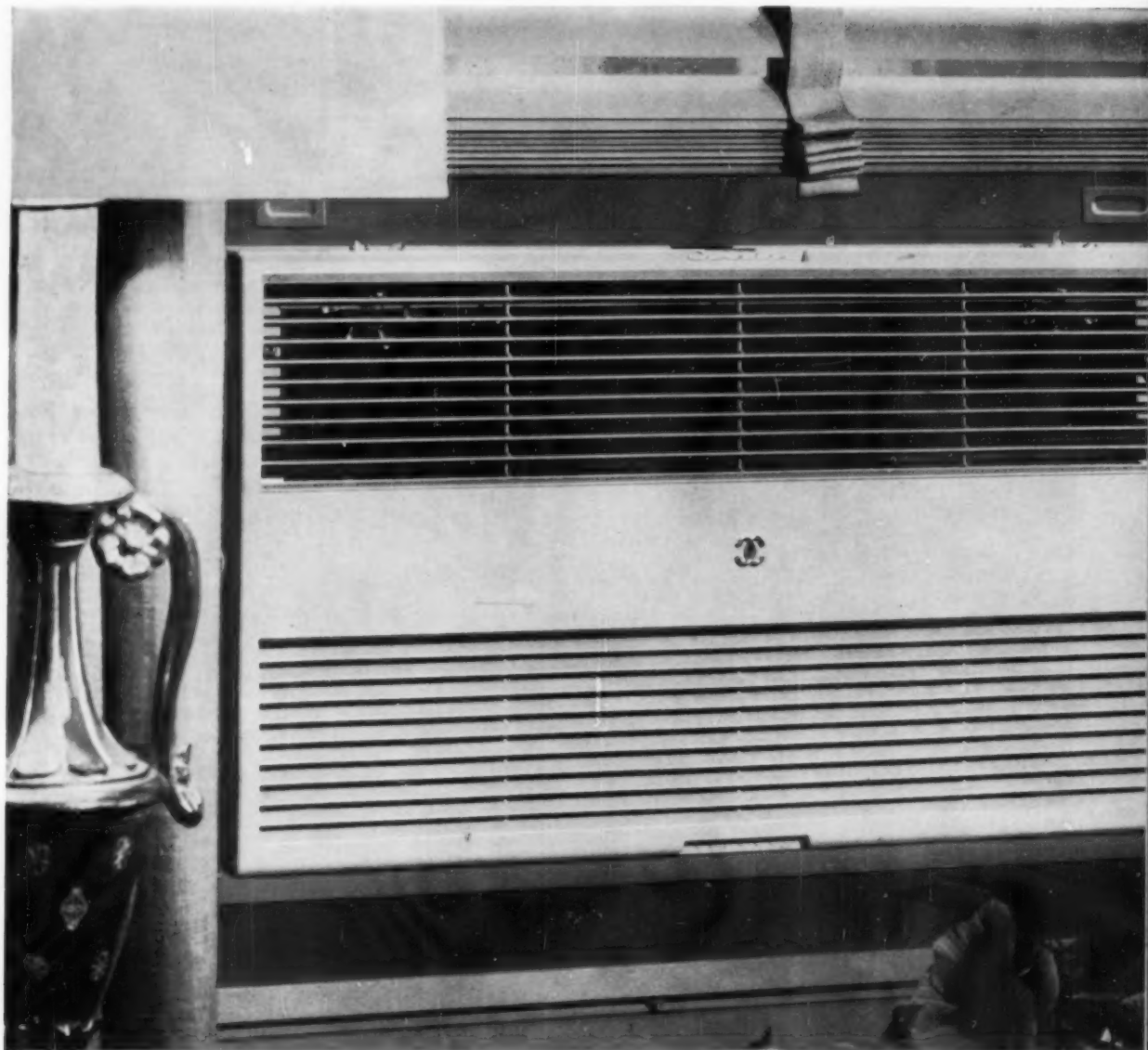
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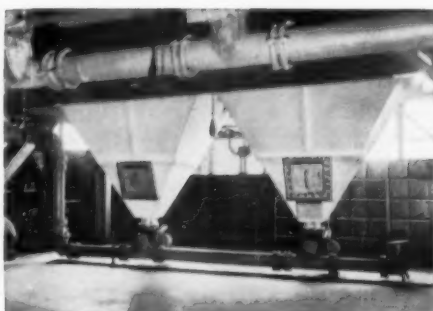


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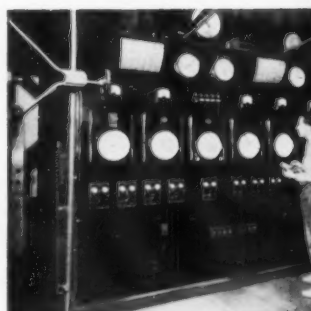




General view of Carrier power plant. Boilers on right are bent tube, two-drum types, by Riley Stoker Corp. burning pulverized coal. Coal moves from bunkers to Riley Pulverizers (at left in photo) and then into furnace.



Mechanical dust collectors by Prat-Daniel Corp. help assure cleanliness of operation. These collectors tie in with United Conveyor ash handling system for movement to ash silo and final disposal.



Pneumatic automatic control panel by Bailey Meter Co. regulates combustion operation of all boilers and auxiliary equipment, maintains continuing steam generation efficiency!

# Carrier puts the chill on fuel costs...with coal

## Air conditioner manufacturer uses coal for low-cost steam

An unusual team—the heating ability of coal and the cooling facility of air conditioning equipment! Yet Carrier Corporation, Syracuse, N.Y., found this combination profitable when expansion plans required additional capacity in its steam plant. After engineering surveys, Carrier decided to continue burning coal for economy of operation. Today modern power equipment supplies steam *economically* for heating, air conditioning and processing. Original fuel costs plus automatic operation within the power plant hold overall steam costs to a minimum.

### Coal is lowest cost fuel

Today, *when the annual cost of fuel often equals the original cost of the boilers*, you should know that bituminous coal is the lowest cost fuel in most industrial areas. And modern coal-burning equipment gives you 15% to 50% *more* steam per dollar, while automatic operation trims labor costs and eliminates smoke

problems. What's more, tremendous coal reserves and mechanized mining procedures assure you a constantly plentiful supply of coal at stable prices.

### Technical advisory service

To help you with fuel problems, the Bituminous Coal Institute offers a free technical advisory service. We welcome the opportunity to work with you, your consulting engineers and architects. If you are concerned with steam costs, write to address below or send coupon. Ask also for our case history booklet, complete with data sheets. You'll find them informative.

### Consult an engineering firm

If you are remodeling or building new heating or power facilities, it will pay you to consult a qualified engineering firm. Such concerns—familiar with the latest in fuel costs and equipment—can effect great savings for you with the efficiency and economy of coal.

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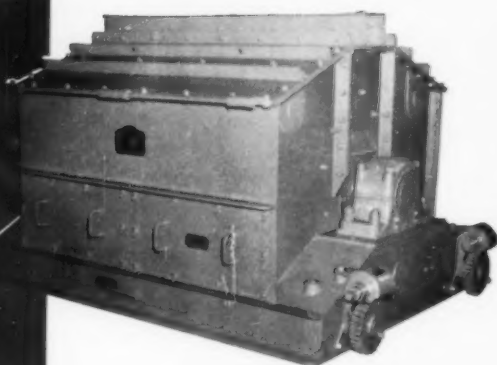
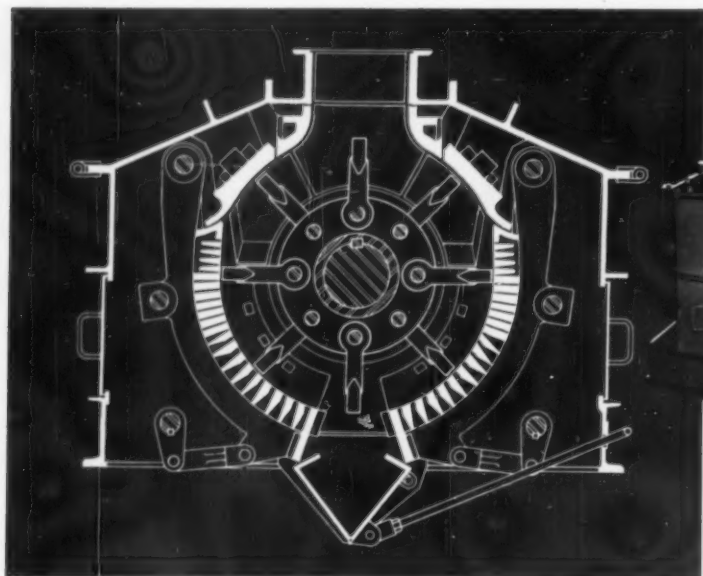
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Coal is loaded into silos before it moves to bunkers. At left is the ash silo which utilizes rotary dustless unloader in loading trucks for disposal. Silos and conveyors are by Fairfield Engineering Co.



## LIKE GETTING TWO CRUSHERS FOR THE PRICE OF ONE

The Pennsylvania Reversible Hammermill gives you so much more for your money. For instance, you get double the crushing area — by merely flipping a switch, the direction of the rotor changes and you are using the breaker blocks and cage bars of a duplicate mill. This not only doubles cage and block life but hammers need never be hand turned and wear is kept uniform. Both cage assemblies are easily adjusted to move towards or away from the hammer circle. This permits you to wear hammers much farther while keeping the grind uniform during the long life of the hammers — with no falling off of tonnage. Send for bulletin 1040 that gives complete information on the various sizes of Pennsylvania Reversible Hammermills. Pennsylvania Crusher Division, Bath Iron Works Corporation, West Chester, Penna.

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BACKS UP OCOTILLO'S  
NEW LJUNGSTROMS®**



*Extremely compact and highly efficient, these baskets of heat transfer surfaces are the heart of the Ljungstrom. (The photo below shows one being lifted into position.) Every inch of these baskets is the approximate equivalent of one foot of a standard tubular heat exchanger. The combined surface of the Ocotillo Air Preheaters provides 263,600 sq ft of heating surface.*



The new Ocotillo Power Plant, near Tempe, Ariz., employs four Ljungstrom Air Preheaters for its two 835,000 lbs/hr boilers. Dependability is built into these Ljungstroms, from their corrosion-resistance to their double-life reversible elements (shown in the photo above).

But one of the most important reasons why Ocotillo chose Ljungstrom is Lifetime Air Preheater Service. Throughout the life of each unit (units dating from 1923 are still in operation), Air Preheater engineers make regular calls to inspect the units and keep them in top operating condition.

What's more, Air Preheater provides rapid factory service, too. Here's an example: a customer called on a Friday morning requesting immediate shipment of cold-end seals for an Air Preheater. But regular fabrication time would take until the weekend, when no ordinary transportation would be available.

So Air Preheater went to work. Spe-

cial trucking was arranged. And by a tremendous effort, fabrication was completed *on the same day the order was received . . .* and the customer received the necessary parts *only ten hours after his initial request.*

Fast response to emergencies and regular inspection throughout the life of each Ljungstrom installation are two of the many advantages Air Preheater provides its customers. Another is expert knowledge of boiler and preheater problems—and how to lick them—gained from over 35 years' experience. Perhaps these reasons explain why nine out of ten preheaters sold today are Ljungstroms.

## **THE AIR PREHEATER CORPORATION**

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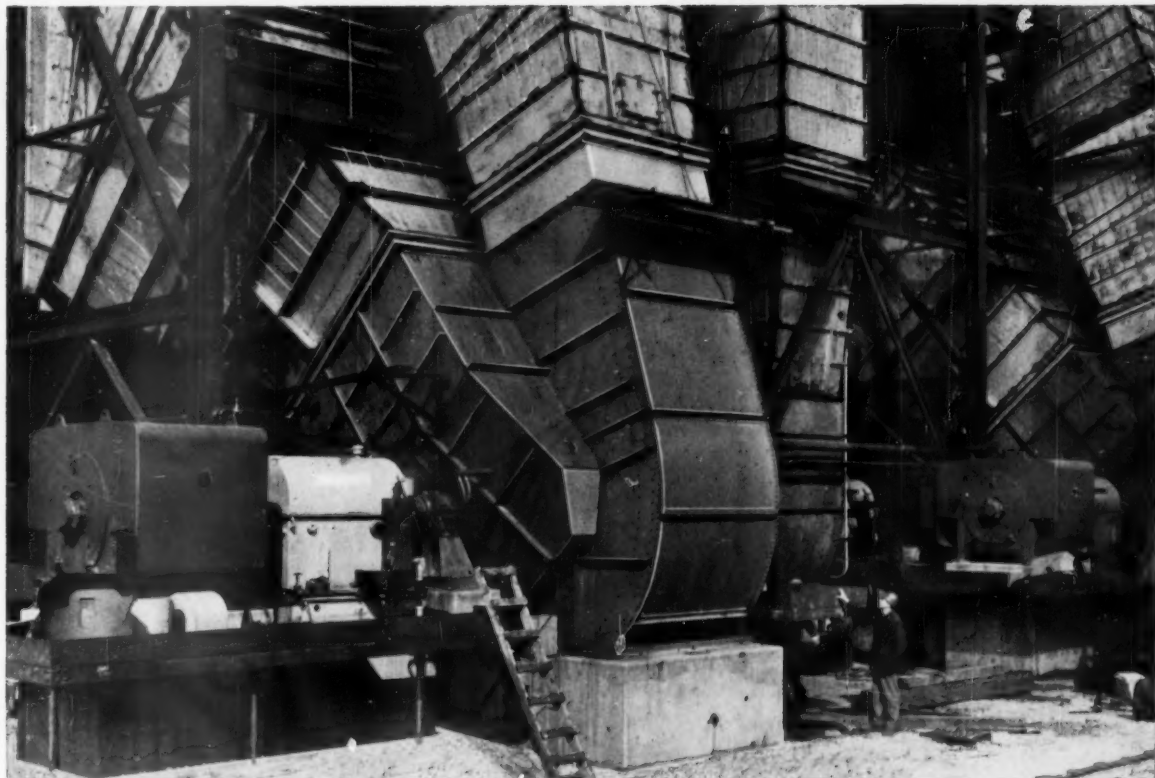
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## **LOOKING FOR PEAK EFFICIENCY OVER BROAD RANGE FOR YOUR DRAFT FANS ?**

### **Here's Why "Buffalo" "BLH" is Best Answer:**

The "Buffalo" Family of "BLH" Fans is designed for highest mechanical efficiency over an extremely broad operating range. Rugged "Buffalo" construction insures economical, dependable operation throughout a long, trouble-free life.

"Buffalo" Type "BLH" features include: streamlined housing designed to deliver ultra-smooth air flow, peak static conversion and pressure distribution at outlet — turbulence minimized by smooth inlet bell, directional inlet vanes, backward-curved blades, matching rotor flange and inlet bell and gradually divergent outlet. These

features all add up to the quiet, powerful, smooth performance characteristic of the "BLH".

Reliable, maintenance-free operation is the result of extra-heavy construction throughout. This includes sturdy steel plate construction ruggedly welded for extra strength — oversized shafts and bearings. Rotors are statically and dynamically machine balanced at factory.

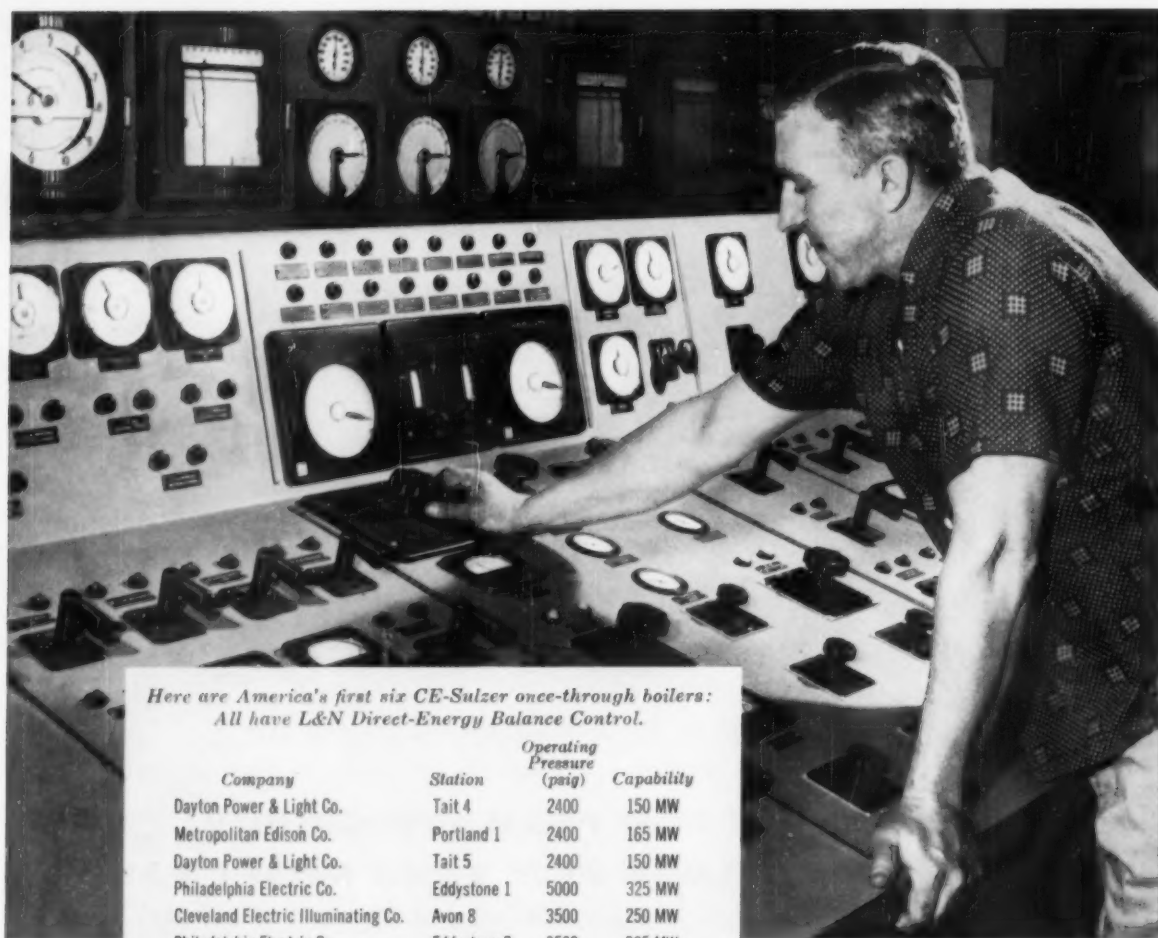
If your mechanical draft conditions require a dependable fan that provides high efficiency over a broad operating range, ask your "Buffalo" engineering representative for complete facts about the "Buffalo" family of mechanical draft fans. Or you can write us direct for Bulletin FD-905.



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COMBUSTION—August 1959



*Here are America's first six CE-Sulzer once-through boilers:  
All have L&N Direct-Energy Balance Control.*

Company	Station	Operating Pressure (psig)	Capability
Dayton Power & Light Co.	Tait 4	2400	150 MW
Metropolitan Edison Co.	Portland 1	2400	165 MW
Dayton Power & Light Co.	Tait 5	2400	150 MW
Philadelphia Electric Co.	Eddystone 1	5000	325 MW
Cleveland Electric Illuminating Co.	Avon 8	3500	250 MW
Philadelphia Electric Co.	Eddystone 2	3500	325 MW

## New L&N Direct-Energy Balance Control Coordinates Once-Through Boiler and Turbine

Metropolitan Edison Company's newest facility, Portland Station Unit No. 1, features a CE-Sulzer once-through boiler and a 165 MW cross-compound axial flow turbine generator. To coordinate the operation of this boiler and turbo-generator, the design engineers employed a new type of combustion control — Direct-Energy Balance.

This D.E.B. Control, developed by Leeds & Northrup, considers the boiler and turbine as an integral unit. From combined steam pressure and generator intelligence, the control coordinates regulation of the fuel input and turbine governor valves.

In the picture above, an operator at Portland is using the D.E.B. Control to set directly the desired rate of

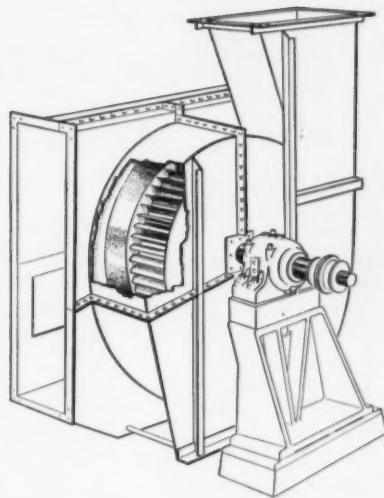
generation change. When he calls for a change in load, the control responds quickly, at the preset rate of change. Operation of the unit is integrated because (1) boiler-turbine output is changed in a predetermined, orderly manner, and (2) output is kept within the capabilities of the equipment in service.

Based on their experiences with field tests on a drum-type boiler at Titus Station, and with Portland 1, Metropolitan Edison Company will specify Direct-Energy Balance Control for a future unit. Although this will be a conventional drum-type boiler, D.E.B. is expected to give better overall operation than conventional combustion control. For further information on D.E.B., contact one of our 34 Field Offices, or write for Reprint 463 (8) to 4972 Stenton Ave., Philadelphia 44, Pa.

Direct-Energy Balance Control...engineered to power plant standards by

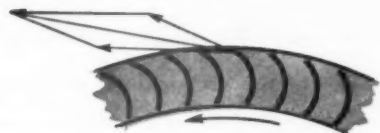


*This is Freeport Sulphur's first-in-the-world offshore sulphur mining plant in Gulf of Mexico, off the Louisiana coast.*



*This is Green's MC type fan, 4 of which were supplied to Freeport Sulphur—each with 54" wheel, producing 67,800 CFM against 18" S.P. at 715°.*

## **FREEPORT SULPHUR'S doing it for the first time in the world! and Green MC type fans will help this gigantic air lift!**



*It's the forward curve at BOTH tip and heel of fan blades that does the job on Green MC type fans.*

Freeport Sulphur had a tough engineering problem.

For their world's first offshore sulphur mining operation, Freeport Sulphur has to compress truly tremendous air volume to air lift liquid sulphur to the surface. Fans are needed for the steam operating unit compressing this air.

Rugged, dependable fans are required. Also, fans that need but a minimum of working space.

Where did Freeport Sulphur get such fans?

Easy — they ordered Green MC type fans. These fans are not only rugged, but the MC is the smallest fan that can be used to perform any required job.

You, too, might solve a vexing engineering problem by calling on Green.



**THE GREEN FUEL ECONOMIZER CO., INC.,**

**BEACON 3, NEW YORK**

# Republic ELECTRUNITE Boiler Tubes

and black liquor fuel . . . produces dependable power at  
**INTERNATIONAL PAPER'S Springhill Mill**

Dependability is important to maintaining production at International Paper Company's Southern Kraft Division at Springhill, Louisiana. Republic ELECTRUNITE® Boiler Tubes were used in the construction of their new power plant.

The boiler installation, designated as a C-E Recovery Unit, was designed and manufactured by Combustion Engineering, Inc., New York City, and installed by International Paper's Engineering Department. Designed to produce an average of 226,000 pounds of steam per hour at an operating pressure of 850 psig, 825°F. The boiler drum is designed for 1,000 psig.

This boiler has a very large furnace and high heat surface necessary to satisfactorily burn black liquor fuel used to produce waste heat and recover valuable chemicals which are reused in the pulp making process. Black liquor fuel is sprayed into the furnace and the boiler is capable of burning 1,500,000 pounds of

dry solids every twenty-four hours.

Republic ELECTRUNITE Boiler Tubes are able to withstand tremendous temperatures because dependability and quality is built-in. ELECTRUNITE is produced from highest quality flat-rolled open-hearth steel and manufactured by Republic's exclusive process that ELECTRICALLY-UNITES the tube under pressure without additional foreign or extra metal. Full normalizing and this process assures uniform wall thickness and diameter, uniform ductility, easy workability, and in-service dependability.

Each length of ELECTRUNITE Boiler Tube is hydrostatically or electronically tested to conform with applicable ASTM specifications, the ASME Boiler and Pressure Code, as well as local, state, and boiler insurance requirements.

To learn more about ELECTRUNITE for boiler, heat exchanger, condenser, or evaporator applications, call your Republic representative. Or, write.

## QUALITY YOU CAN MEASURE . . .



**FARROWTEST REJECT TABLE**

Wall Thickness (B.W. Gage)	Minor dimension of the defect (Length or Depth)	Defective Area (Length, Depth Plane)
20	.006"	.0025 sq. inches
18	.006"	.003 sq. inches
16	12 1/2 % of wall	.003 sq. inches
14 and 13	12 1/2 % of wall	.004 sq. inches
12 and heavier	12 1/2 % of wall	.005 sq. inches

FARROWTEST detects and rejects not only tubing containing defects which completely penetrate the wall; but also tubing with defects equal to, or greater than, those shown in this table. For irregular defect shapes, a tube with defect area equal to or greater than shown above is rejectable. Where required, sensitivity of FARROWTEST equipment can be calibrated to reject defects of lesser specified area than shown in table, at extra cost.



REPUBLIC ELECTRUNITE STAINLESS STEEL HEAT EXCHANGER TUBING resists corrosion and provides long trouble-free service for main surface condensers in utility power plants where water is used directly from natural sources. If you have a water problem, call your Republic representative.

◀ **FARROWTEST®—QUALITY YOU CAN MEASURE.** Not a laboratory theory, not a mere inspection tool, but an exclusive production test that detects and rejects tubing containing defects of critical size. FARROWTEST is offered as an alternative to other less positive tests in accordance with the table, left, at no extra cost.





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Please send more information on the following products:

- ☐ Republic ELECTRUNITE Boiler Tubes
- ☐ Republic ELECTRUNITE Heat Exchanger Tubes
- ☐ Carbon ☐ Stainless ☐ FARROWTEST Brochure

Name \_\_\_\_\_ Title \_\_\_\_\_

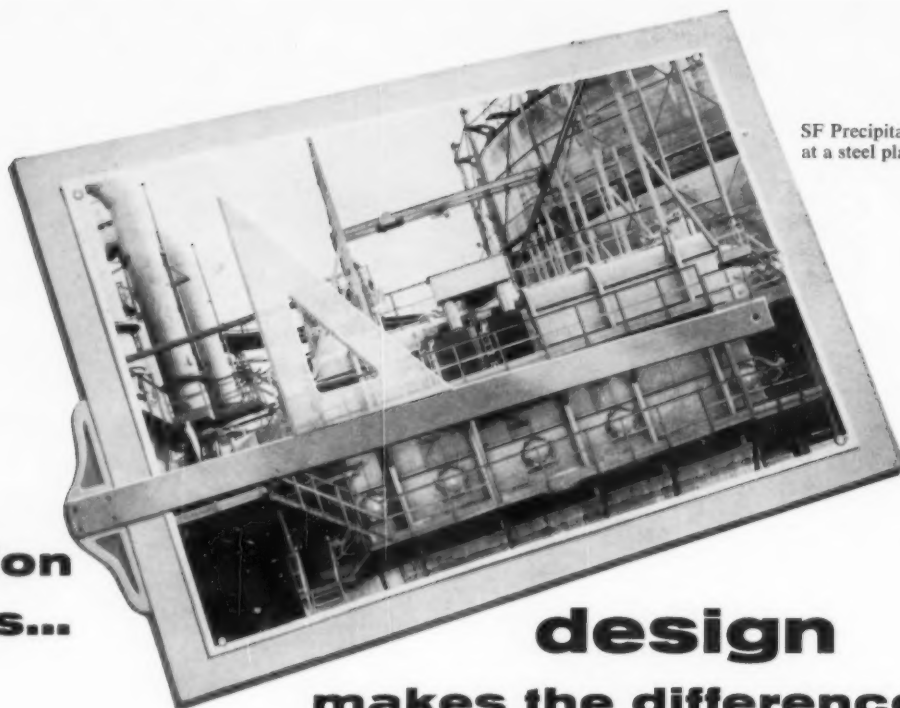
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SF Precipitator  
at a steel plant.

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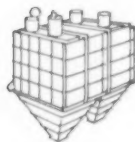


**design  
makes the difference**

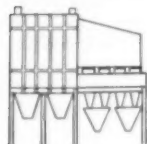
**Higher efficiency** of Buell 'SF' Electric Precipitators is the result of exclusive engineering features. For example, Buell's *Spiralelectrodes* emit 50% to 100% more electrons than other types . . . and *maintain* their efficiency. Positive gas flow control through adjustable baffles prevents scouring and eddying. And Buell's Unique Continuous Cycle Rapping practically eliminates "puffing".



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### This Changing World

No individual can state for certain just when the ways of life by which he had been raised became passé. We sat in on the Education in Materials symposium at the Annual Meeting of the ASTM, Atlantic City, this past June and heard that fact of life as it applies to us brought home time and again. In fact, we experienced a decided "hurrah for our side" emotion at certain of the remarks of W. T. Alexander, dean of engineering, Northeastern University, and president of the American Society for Engineering Education. His heartwarming (to us at least) admonition to educators pushing for rapid transitions toward a more theoretically oriented engineering curriculum from the one we had all experienced was based upon two principal points:

"1. The engineers whom we have been, and are, graduating are not failures. They have been and are contributing relatively well to our progress, and certainly the techniques which they now use are very different from those which they studied in college. We are obviously dealing with a group of people who are very adaptable. Furthermore, we cannot hope to teach them what they will need to know over the next 25 years. This leads to the second point:

"2. The way we teach the subject matter in our respective colleges, whatever its intrinsic nature may be, will have more to do with the eventual success of our graduates than the particular subjects which they study or to what degree they are theoretically oriented."

Both these points we feel are sound ones and well

presented. Yet we must agree with the general tone of the symposium that we needs must progress toward a more theoretically oriented curriculum. This is true mostly because we have exhausted the empirical method advancement and now must fall back upon a knowledge of the materials we have at hand or can develop to effect new advances. K. B. Woods, outgoing president of the ASTM, at the President's Luncheon underscored this need with the statement: "In my opinion engineering in all of its branches has undergone more fundamental changes during the past seven or eight years than had occurred during the previous thirty years or so."

Within our limited knowledge of the last decade's progress in the power field alone this statement is an accurate one. The amazing ingenuity of our father's time called Yankee ingenuity is no longer enough to meet the demands of nuclear energy or higher temperature and pressure steam cycles. Fundamental data on properties of material, obtainable only from years of assiduous study, will be the raw material the ingenious mind of the late today and tomorrow will apply to solve the problems of his time.

The well-trained, intensive mind that will be drawn to engineering under this set of operating rules will require some adjustments on the part of management to hold its interest and further its value to industry's needs. We recommend consideration of the article on page 53 in this issue which we believe part and parcel of this recognition of our changing world.

High and low temperature corrosion causes are outlined and the role of vanadium specifically studied. Experiences with dolomite injections on pilot scale superheater steel operating under elevated temperatures are reported as well as test results of additives including ammonia as weapons for combating low temperature corrosion under laboratory conditions.

BY L. K. RENDLE,<sup>†</sup> R. D. WILSDON<sup>†</sup> AND  
G. WHITTINGHAM<sup>††</sup>

British Petroleum Co., London, England

## Fire Side Corrosion in Oil-Fired Boilers\*

**F**OULING and corrosion of heating surfaces in modern boiler plants impair efficiency and availability for service and a survey of world literature indicates that difficulties from these causes have been experienced on a wide range of boilers and with solid and liquid fuels. The problems do not appear to be acute, however, in small heating and industrial boilers, and attention has been confined almost entirely to their incidence in steam power plants.

Many of the investigations carried out in the past into the causes of deposition and corrosion were concerned with solid-fuel fired plants. In view of the rapidly increasing use of residual fuel oil, particularly on boilers of advanced superheat and low exit gas temperatures, emphasis in recent research has been on corrosion by products from fuel oil combustion.

Two distinct types of corrosion occur, according to the temperature of heat exchange surfaces affected. Analyses of the normally thin, hard deposits in the superheater zone of oil-fired installations show that the major components are low-melting complexes of vanadium, sodium and sulfur.

Low temperature corrosion of economizers, air heaters and stacks is associated with the condensation of sulfuric acid from flue gases when the metal temperature falls below the acid dewpoint. Many papers have been written on this particular aspect of the overall corrosion problem, and the formation of sulfuric acid is attributed either to oxidation of sulfur dioxide by atomic oxygen formed in the combustion process (1),<sup>1</sup> or to the catalytic action of ferric oxide (2), at temperatures in the range 900–1200 F.

High temperature corrosion is to a large extent dependent (3) on the composition and quantity of ash formed during combustion. The major non-hydrocarbon constituents of fuel oil are complexes of vanadium, nickel and iron in the form of oil soluble porphyrins, organic sulfur compounds and chlorides and sulfates of sodium and calcium in suspension (4–6).

The nature of the metal complexes makes it extremely difficult to remove them economically by fuel treatment. Therefore, to overcome high temperature corrosion, two courses of action are possible:

1. To select suitably resistant materials of construction, and judicious design to ensure that the selected alloys operate within their safe temperature ranges where corrosion is not likely to be catastrophic.
2. To use suitable additives to mitigate corrosive attack by modifying the composition of ash deposits.

In the choice of materials of construction in the superheater zone, the tubes do not present as big a problem as hangers and spacers. In many boilers, even of current design, the hangers and spacers are not normally cooled and will be at substantially higher temperature than the superheater tubes. It is necessary, therefore, to select special heat resistant materials for tube supports and spacers (7, 8).

Three main approaches to the problem of high temperature corrosion by combustion gases have been employed; long term plant investigations, laboratory crucible tests with synthetic and prepared ashes and the use of small scale rigs.

The first part of this paper deals with work which falls into the last category, and is concerned mainly with the assessment of a range of superheater and structural steels in respect to corrosion by combustion of low and high vanadium fuels oils. These studies form part of a comprehensive research program to investigate the effects of fuel type, combustion conditions and additives on the corrosion of a wide range of steels at elevated temperature.

The second section reviews the results of full scale and

\* Presented before the 1959 Fifth World Petroleum Congress, New York, N. Y. Permission granted to publish after May 30, 1959.

<sup>†</sup> Applied Physics Section, Research Centre.

<sup>††</sup> Technical Services Branch.

<sup>1</sup> Numbers in parentheses refer to List of References at the close of the article.



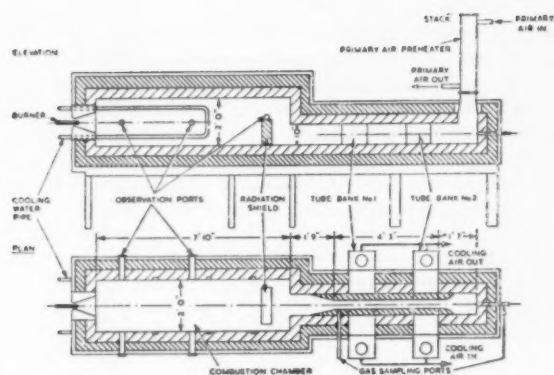


Fig. 1—General arrangement of experimental furnace for high temperature corrosion studies

TABLE I—INSPECTION DATA ON FUEL OILS

	Low Vanadium Fuel	High Vanadium Fuel
Specific gravity at 60 F/60 F	0.9435	0.9630
Specific gravity at 140 F/60 F	0.9150	0.9350
Flash point (PM Closed), F	220	192
Gross calorific value (calculated), Btu/lb	18,370	18,560
Total sulfur content, % wt	3.28	2.52
Kinematic viscosity at 140 F, cs	51.17	57.98
Kinematic viscosity at 170 F, cs	27.04	30.91
Kinematic viscosity at 210 F, cs	14.08	15.40
Pour point (upper), F	45	...
Carbon residue (con), % wt	8.95	9.6
Asphaltenes, % wt	1.74	5.0
Asphaltum (soft), % wt	7.63	5.8
Total acidity, mg. KOH/g	0.12	0.05
Mineral acidity, mg. KOH/g	Nil	Nil
Ash content at 550 C (1022 F), % wt	0.029	0.0895
Water content, % vol	0.5	0.10
Water and sediment, % vol	0.6	0.25
Sediment by extraction, % wt	0.006	0.02
Salt content, % wt	0.008	0.010
Carbon, ultimate analysis, % wt	84.74	85.6
Hydrogen, ultimate analysis, % wt	11.32	10.9
V <sub>2</sub> O <sub>5</sub> in ash, % wt on oil	0.0085	0.0513
NiO in ash, % wt on oil	0.0018	0.0055
Fe <sub>2</sub> O <sub>3</sub> in ash, % wt on oil	0.0013	0.0011
CaO in ash, % wt on oil	0.0013	0.0011
Al <sub>2</sub> O <sub>3</sub> in ash, % wt on oil	0.0011	0.0004
Na <sub>2</sub> O in ash, % wt on oil	0.0047	0.0055
SiO <sub>2</sub> in ash, % wt on oil	0.0042	0.0005
SO <sub>2</sub> in ash, % wt on oil	0.0079	0.0092
Vanadium content, ppm on fuel oil	48	287
Sodium content, ppm on fuel oil	35	41

pilot scale investigations designed to provide information on the degree of formation of sulfuric acid in oil-fired

boilers and the efficacy of operational and other methods of controlling low temperature corrosion.

### Part 1—High Temperature Corrosion Studies

#### EQUIPMENT

Tests were carried out on a small oil-fired furnace, illustrated in Fig. 1. The essential feature was a combustion chamber, fitted with a water cooled coil to provide control of gas exit temperature, which supplied flue gases to a narrow, refractory-lined channel. Tubes of superheater steel specimens were inserted through the channel to provide two banks, each containing twelve tubes. Each tube was fitted with a chromel-alumel thermocouple welded into the tube wall at the center, and was installed so that the thermocouple weld faced upstream. The tubes were cooled internally with air from a centrifugal blower and the desired tube temperatures obtained by manual control. Small specimens of heat resisting alloys in the form of rectangular blocks were placed in the narrow gas channel between the two tube banks and, in some runs, also after the second bank. These specimens were uncooled and were fixed in a thin layer of refractory cement to maintain a constant vertical position.

Fuel oil was supplied from a day tank through a thermostatically controlled preheater to a burner of the low pressure air-atomizing type. Close control of air and fuel could be maintained to give constant flame length and combustion conditions. Primary air to the burner was supplied from a preheater located after the second bank of tubes.

Sheathed Pt-Pt/Rh thermocouples were placed at the entrance to the refractory-lined channel and between the tube banks. Sampling ports were also provided before and after the tube banks for use with a continuous oxygen recorder or for the withdrawal of gases for measurement of dewpoint and rate of acid build-up. Gas and tube metal temperatures, oil feed and preheated air temperatures were measured on a ten point Speedo-max recorder.

#### MATERIALS

##### Fuel Oils

Two fuel oils of nominal viscosity 650 sec. Redwood 1 at 100 F, one with a low vanadium and the other with a high vanadium content, were used. Inspection data are given in Table I.

##### Superheater Steel Tubes (1 3/4 inches OD)

- 18/11 Cr/Ni; Nb stabilized (British)
- 17.5/11 Cr/Ni; Nb stabilized (Swedish)
- 13.5 Cr
- 2 1/4/1 Cr/Mo (British)
- 2 1/4/1 Cr/Mo (Swedish)
- 1 1/2 Cr/Mo (British)

##### Heat Resisting Alloys

- 20/7 Cr/Ni
- 25/20 Cr/Ni
- 60/12 Ni/Cr
- 25/12 Cr/Ni
- 53/18 Ni/Ci

Detailed analyses of the different steels and alloys are given in Tables III and IV.

##### Dolomite

Swedish: MgO content 14 per cent by weight: particle size, average 100 microns, maximum 250 microns.

Norwegian: MgO content 21 per cent by weight: particle size, average 15 microns, maximum 74 microns.

#### EXPERIMENTAL

Before insertion in position through the side of the refractory-lined channel the steel tubes were accurately

TABLE II—MEAN OPERATING CONDITIONS

Temperatures (°F)	
Combustion chamber	1940
Flue gas before No. 1 bank	1860
Flue gas between banks	1500
Flue gas after No. 2 bank	1120
Oil to burner	194
Air to burner	256
Gas analysis	
O <sub>2</sub> in flue gas before No. 1 bank (% vol)	4.5
Fuel oil flow rate (IG/hr)	2.87

measured. The heat resisting alloys were weighed before being placed in position.

The furnace was lighted on gas oil, and the feed changed to fuel oil when the furnace temperature reached about 1500 F, usually some three hours after start-up. When established, the fuel oil flame was about 4 feet long and almost transparent. It was not possible to achieve reasonably steady tube temperatures at the desired level until after eight hours operation on fuel oil because of the individual supply of cooling air to each tube and heating of refractory walls. Tube temperatures were normally measured once a day.

The tests with low vanadium fuel oil were of 650 hours duration and typical mean operating conditions over a run are shown in Table II.

In the tests with high vanadium fuel oil, the same general procedure was followed, but the runs were only of 200 hours duration. The first run served as a control and in subsequent runs powdered dolomite was fed continuously from a vibrating tray through the air register into the flame. The fuel flow rate was 2.9 IG/hr and dolomite injection rate 75 g/hr corresponding to an addition of 0.06 per cent by weight of fuel.

In all tests the pressure drop across the tube banks was measured to provide an indication of rate of fouling. Dewpointmeter readings were taken at intervals by extracting gases through the sampling ports situated before and after the tube and passing them over the probe head. The instrument used was of the BCURA type (9).

#### EXAMINATION OF STEELS AND ALLOYS

At the completion of a run the rig was allowed to

cool down and the top of the refractory channel removed. The tube banks were photographed *in situ*. The tubes were removed one by one working from the top downward, any loose deposit being removed and bottled.

The central section, four inches long, which had been exposed to the flue gases was cut out of each tube and then cut in half through the thermocouple weld at right angles to the tube axis. One-half was reserved for metallographic analysis and the other was descaled. The initial descaling was mechanical and as much as possible of the scale was collected and added to the deposit already taken from the tube. The specimens were finally descaled by a chemical method described in Appendix. Each descaled section was measured and the depth of metal loss calculated from the original measurements.

The heat resisting alloy specimens were descaled in a similar manner after loose deposit had been removed. The descaled specimens were weighed and the corrosion loss calculated. A small portion was removed for metallographic examination before chemical descaling.

#### Results

##### BEHAVIOR OF SUPERHEATER STEELS AND ALLOYS; LOW VANADIUM FUEL

The physical characteristics and chemical analyses of deposits on the tube banks are shown in Table III, together with the operating temperature, composition and calculated rate of corrosion. The latter is expressed in in./yr by linear extrapolation from a 650 hour test period.

X-Ray analyses of the deposits showed the presence of large amounts of iron oxide. The diffraction patterns were complex and a considerable amount of work for calibration purposes is required before more complete identification of minor constituents can be given.

The heat resisting alloy specimens after a 650 hour run and descaling with corrosion rates calculated from loss in weight on descaling are given in Table IV, together with analyses of scales adhering to the specimens.

X-Ray analysis of the very thin scale deposits disclosed the presence of over 90 per cent of iron oxides, but

TABLE III—DEPOSITS AND CORROSION RATES: LOW VANADIUM FUEL OIL

Tube No.	Tube Bank	Composition, % Wt.			Country of Origin	Mean Tube Metal Temperature, °F	Deposits	Analysis, % Wt.			Calculated Penetration In./Yr
		Cr	Ni	Mo				V	Na	S	
1	1	13.5	—	—	Sweden	1112	Adherent scale, up to 0.02 in. thick under black red crystalline deposit	15.9	3.8	3.7	0.034
2	1	17.5*	11	—	Sweden	1112	Easily removable deposit over thin hard scale 0.015 in. thick	15.2	6.2	7.7	0.034
3	1	18*	11	—	Britain	1202	Thin, hard black crystalline deposit over thin hard scale 0.02 in. thick	12.0	3.9	ND	0.026
4	1	2.25	—	1	Sweden	1022	Black red crystalline deposit with nodules covering loose thick scale and pits. Mean pit depth 0.01 in.	15.4	3.7	6.1	0.061
5	1	2.25	—	1	Britain	1112	Red crystalline deposit adhering strongly to hard, brittle scale up to 0.025 in. thick	—	—	—	0.044
6	1	1	—	0.5	Britain	1112	Hard black deposit adhering to thick scale easily flaked off. Scale thickness 0.08 in.	11.0	6.0	9.6	0.128
7	2	13.5	—	—	Sweden	1022	Brown red deposit adhering to thin hard tenacious scale	2.1	1.3	2.2	—
8	2	18*	11	—	Britain	1202	Small amount of deposit, very thin, hard, tenacious scale	12.0	3.9	ND	00.02
9	2	17.5*	11	—	Sweden	1022	Little deposit. Very thin, hard tenacious scale	12.1	5.5	8.4	0.010
10	2	2.25	—	1	Britain	1022	Brown red adherent deposit over hard brittle scale up to 0.015 in. thick	14.7	3.5	7.5	0.041
11	2	1	—	0.5	Britain	1022	Red deposit strongly adherent to hard, brittle scale up to 0.025 in. thick	11.0	6.0	9.6	0.020
12	2	2.25	—	1	Sweden	932	Brown red deposit adhering to thin hard tenacious scale	17.8	4.2	5.7	0.034

\* Niobium stabilized.

TABLE IV—HEAT RESISTING ALLOYS; LOSS IN WEIGHT AND ANALYSIS OF SCALES PRODUCED AT 1500 F  
Low Vanadium Fuel; Length of Run—650 Hours

Specimen No.	Composition, % Wt						Weight Loss, G/Cm <sup>2</sup>	Analysis of Scale, % Wt		
	C	S	Si	P	Mn	Cr		V	Na	S
1	0.37	0.020	1.63	0.026	0.66	20.0	7.2	0.155	—	—
2	0.37	0.025	1.17	0.02	0.80	25.9	18.5	0.099	0.4	0.22
3	0.36	0.029	1.18	0.020	1.25	11.9	39.5	0.374	1.3	0.37
4	0.38	0.034	0.75	0.021	0.73	25.2	12.7	0.085	2.8	0.95
5	0.88	0.061	2.01	0.018	0.71	18.4	53.5	0.102	—	—

no other constituent could be determined quantitatively. The scales from the three specimens, 1, 2 and 4, contained both magnetic oxide  $\text{Fe}_3\text{O}_4$  and  $\alpha\text{-Fe}_2\text{O}_3$ , but in those from the two high nickel alloys, 3 and 5, only  $\text{Fe}_3\text{O}_4$  was found.

Metallographic analysis of the tubes showed the following main features:

#### 1 Per Cent Cr

The microstructure consisted of the normal ferrite and pearlite, but with the grain size somewhat enlarged under the influence of heat. As with all the tubes, the metal was modified in the heat-affected area of the thermocouple weld.

#### 2 1/4 Per Cent Cr

The microstructure was only affected in the weld zone; some increase in grain size had occurred in the heated zone. The British steels had a much larger grain size than the Swedish but their resistance to corrosion was about the same.

#### 13.5 Per Cent Cr

The corrosion rate was less than that of the low chromium content steels. Normal microstructures were found and the hot zone material was little different from the unaffected metal.

#### 17.5/18 Cr: 11 Ni

These showed least corrosion. It was not possible to polish the specimens sufficiently for good photomicrography, but all displayed normal microstructures. Twinned austenite was present in both heated and unaffected metal.

The results of the metallographic examination of the

alloy specimens are described in detail in Appendix II.

#### BEHAVIOR OF SUPERHEATER STEELS: HIGH VANADIUM FUEL

Three runs, each of 200 hour duration, have been made so far. The first was a control to determine the influence of the high vanadium content on corrosion and deposition. The second and third were carried out with injection of Swedish and Norwegian dolomite respectively.

The same combustion conditions were maintained as in the run with low vanadium fuel and the tube metal temperatures were generally in the same range. Some of the high Cr steels in the first two rows were, however, maintained at temperatures of 1202 F and 1292 F. In the control run, the pressure drop across Bank 1 and across both banks showed little tendency to increase Fig. 2, and the tubes at the end of the run were covered with relatively thin but hard scales.

With injection of Swedish dolomite, the pressure drop began to increase very rapidly after about 150 hours, Fig. 3, and it was doubtful if the run could have been extended much beyond the 200 hour test period without enforced shut down. Examination of the tubes showed that heavy deposition had occurred with almost complete bridging across the gas passes through the front rows. The deposits were extremely hard and wedge shaped with maximum thickness of 1 inch.

The effect of injecting Norwegian dolomite, with a higher magnesium content, was to bring about a steady increase in pressure drop almost to the same high value attained with Swedish dolomite. Heavy deposition had again occurred, but the deposits were much softer and less adherent. "Cracking off" occurred when the tubes cooled down.

Complete analyses of deposits and corrosion rates for

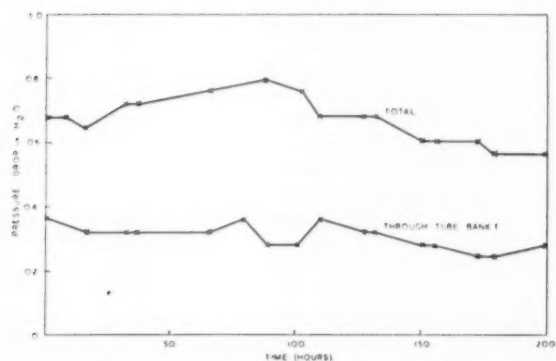


Fig. 2—Pressure drop readings during 200 hr run with high vanadium fuel: no additive. Note that there was very little tendency for the pressure drop to increase

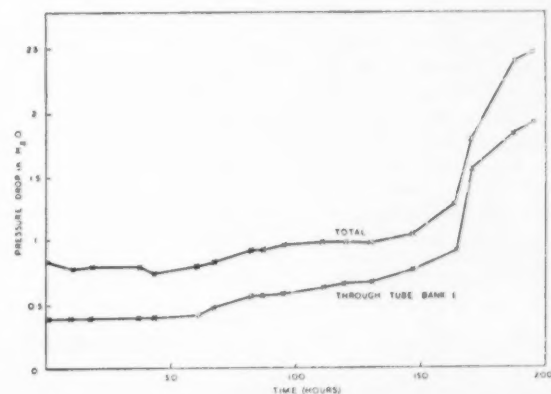


Fig. 3—Pressure drop readings with high vanadium fuel and dolomite injection to furnace

TABLE V—EFFECT OF DOLOMITE INJECTION ON CORROSION OF SWEDISH SUPERHEATER STEELS HIGH VANADIUM FUEL OIL

Tube Material	Tube No.	Tube Bank	Mean Temperature, F	Corrosion Rate, in./Yr		
				No Additive	Swedish Dolomite	Norwegian Dolomite
17 1/2 Cr 12 Ni	1	1	1292	0.176	0.107	0.122
	4	1	1202	0.2	0.069	0.078
	13	2	1112	0.056	0.04	0.049
	2	1	1292	0.14	0.033	0.077
13 1/2 Cr	7	1	1202	0.074	0.037	0.059
	15	2	1112	0.059	0.019	0.037
	3	1	1112	0.056	0.211	0.129
	8	1	1022	0.045	0.062	0.086
2 1/2 Cr 1 Mo	14	2	932	0.065	0.064	0.109
	6	1	1112	0.062	0.118	0.051
	9	1	1022	0.04	0.050	0.059
	20	2	932	0.027	0.031	Nil

all tubes are not yet available. Corrosion data for Swedish steel tubes are given in Table V.

#### DEWPOINTMETER READINGS

When low vanadium fuel oil was burned, the acid dewpoint of the gases leaving the combustion chamber was 300 F and this increased very slightly after the tube banks. The rate of acid build-up showed the usual variation with detector probe temperature (9), maximum values being obtained at about 250 F. Very high rates of build-up were measured, the values obtained on the gases after the tube banks being about 30 per cent higher than those recorded on the combustion chamber exit gases.

With the high vanadium fuel oil the acid dewpoint was lower, about 280 F, but the rate of acid build-up remained high. The effect of dolomite injection was to reduce the dewpoint 10–20 F, greater reduction occurring with Norwegian dolomite, and to halve the maximum rate of build-up at 40 F below the dewpoint.

#### Discussion

Once the desired operating conditions were reached the rig was stable and easy to run. As the temperature of the gases entering the tube banks was above 1800 F and the calculated gas velocity across the tubes in excess of 30 ft/sec, the conditions in the high temperature zone were similar to those in the superheater passes of full scale plants.

At the end of all runs the tubes in No. 2 bank appeared to be in much better condition than those in the first bank. The data in Tables III and V show that, in general, increase in both gas and tube metal temperature produced an increase in rate of corrosion. The lowest degree of corrosion, at the same metal temperature, was shown by the four stainless steels.

At the present stage of the work it is not possible to make a direct comparison between the corrosive effects of products of combustion from low vanadium fuel oil and those from high vanadium fuel oil because of the different test periods with the two types of fuels. It will be noted that the rates of corrosion, quoted in in./yr, were in the former case extrapolated from a 650 hour run and in the latter from 200 hour runs. Linear extrapolation has been used, but it is quite probable in view

of the production of hard compact scales, that the rate of corrosion follows a parabolic law. Also, in the runs with high vanadium fuel oil only in a few instances were tubes of a given material maintained at the same temperature as in the tests with low vanadium fuel oil.

From Table IV, it is seen that specimen No. 3 had the highest weight loss when subjected to the products of combustion of the low vanadium fuel. This behavior is consistent with the findings of other workers (7, 8, 10), who reported that the behavior of high nickel alloys is not satisfactory in the presence of relatively high concentrations of sulfur oxides. The other high nickel alloy, No. 5, had a lower corrosion rate, probably because of its higher silicon content (8).

When the three high Cr alloy specimens were examined it was noted that corrosion was mainly confined to the small section of the specimens which had been embedded in refractory cement. The two high nickel alloys were relatively unattacked in this zone but suffered much greater corrosion on their exposed surfaces.

The results in Table V show that, when operating with high vanadium fuel, the injection of dolomite reduced corrosion of the high Cr steel tubes two or three fold. On the other hand, the rate of corrosion of the low Cr steels appeared to be slightly higher with dolomite injection. In the absence of chemical and x-ray analyses it is not possible to put forward an explanation for this apparent anomaly.

With the high Cr steels, Swedish dolomite gave slightly better protection against corrosion than Norwegian dolomite of higher magnesium content. On the other hand, the deposits from the use of Swedish dolomite were extremely hard and produced rapid blockage. The work to date suggests that fouling is likely to be a problem when dolomite is used on boilers of advanced superheat in which high vanadium fuel oil is burned. The use of a grade with high magnesium content will, however, tend to produce softer and less adherent deposits, more easily removed by soot blowers.

It can also be concluded that: (a) for superheater tubes operating at 900–1300 F, the corrosion resistance increases with increasing Cr content; (b) for uncooled heat resisting alloys at about 1500 F stainless steels are more resistant than nickel based steels to the products from low vanadium, high sulfur fuel oil.

## Part 2—Low Temperature Corrosion

### FORMATION AND BEHAVIOR OF SO<sub>3</sub>

The concentration of SO<sub>3</sub> in the flue gases from oil-

fired installations depends on several factors, including the sulfur content of the oil used, the flame temperature, the air/fuel ratio and the extent of catalytic sur-



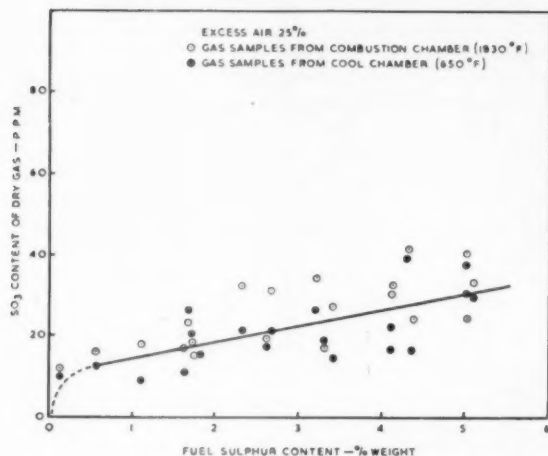


Fig. 4—Experimental furnace—variation of  $\text{SO}_2$  content of flue gas with sulfur content of fuel

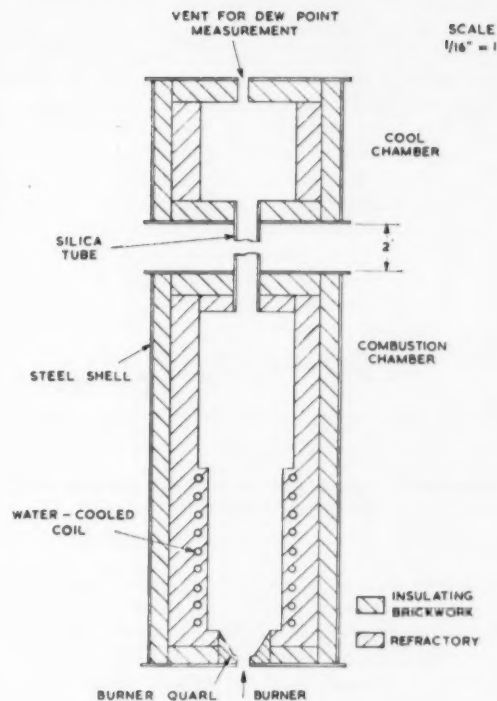


Fig. 5—Plan of experimental furnace

faces present, and can therefore vary considerably between different installations (12).

The results shown in Fig. 4 were obtained on the small refractory-lined furnace illustrated in Fig. 5 and which has been described in detail elsewhere (13). The furnace was operated at 25 per cent excess air and with a combustion chamber exit gas temperature of 1830 F. A variety of fuel oils of different sulfur content was used and intermediate sulfur concentrations were obtained by blending with carbon disulfide.

The  $\text{SO}_2$  content of the gases increased from 10 ppm for gas oil of 0.12 per cent by weight sulfur to 40 ppm for fuel oil containing 5 per cent sulfur. The percentage conversion of sulfur to  $\text{SO}_2$  (Fig. 6) decreased with increasing sulfur content and fell almost linearly from 2 per cent with fuel containing 1.5 per cent sulfur to 1 per cent conversion with a 5 per cent sulfur fuel oil.

Over the last two years tests have been in progress on a marine type, water tube boiler (Fig. 7) of maximum rating 85,000 lb/hr to determine the effects of burner type, operating conditions, and additives on the corrosive nature of the gases. The results of  $\text{SO}_2$  determinations

on the gases from the combustion of fuel oil containing 2.8 per cent sulfur are shown in Table VI.

Similar conversions of sulfur to  $\text{SO}_2$  have been reported by Corbett (14) and, more recently by Jarvis (15).

Corrosion probe results are given in Fig. 8. The determinations were made at positions before and after the air heater, and it was found that the level of corrosion after the air heater was considerably higher than that upstream of the air heater at the same probe temperatures.

Higher dewpoints and rates of acid build-up were also obtained on flue gas at the air heater outlet, Table VII.

Similar results have been obtained on other installations, and from the corrosion probe and dewpointmeter readings it would appear that further production of  $\text{SO}_2$  was occurring in the air heater.

Anderson and Manlik have shown recently (16) that when  $\text{SO}_2$  was introduced into different zones of a small oil-fired boiler, the amounts of corrosion produced in each section, including the stack, were approximately equal. A major conclusion was that catalytic oxidation of  $\text{SO}_2$  by fuel ash constituents could occur, even at

TABLE VI— $\text{SO}_2$  CONCENTRATION IN GASES FROM MARINE-TYPE BOILER

Boiler Load 1000 Lb/Hr	$\text{CO}_2$ % Mol	$\text{O}_2$ % Mol	$\text{SO}_2$ Ppm	$\text{SO}_2$ Ppm	Position
77	11.6	5.6	932	8	Air heater outlet
74	11.6	5.6	1006	11	Air heater outlet
75	12.6	4.2	1140	8	Air heater outlet
80	12.6	4.2	1000	7	Air heater inlet
76	11.2	5.0	1015	14	Air heater inlet
74	11.2	6.0	1244	14	Air heater inlet
77	11.2	6.0	1030	16	Air heater inlet
79	11.8	4.7	1170	17	Air heater outlet
79	11.8	4.8	1170	16	Air heater outlet
79	11.2	5.6	1170	12	Air heater outlet
169	10.8	6.4	1040	10	After I.D. fan
76	10.8	6.4	1191	14	Air heater outlet
82	10.8	6.2	1164	18	Air heater inlet

TABLE VII—ACID DEWPOINTS AND RATES OF ACID BUILD-UP ON MARINE-TYPE BOILER

Sampling Point	Rate of Acid Build-Up (as $\mu$ a/Min)			
	Dewpoint, °F	167 F	194 F	230 F
Air heater inlet	200	132	44	...
	205	114	...	...
	230	103	32	<1
	230	148	30	<1
Air heater outlet	268	...	34	31
	272	...	62	52
	274	108	89	74
	285	160	168	90
	284	110	138	68
	284	125	128	103
	284	...	46	25

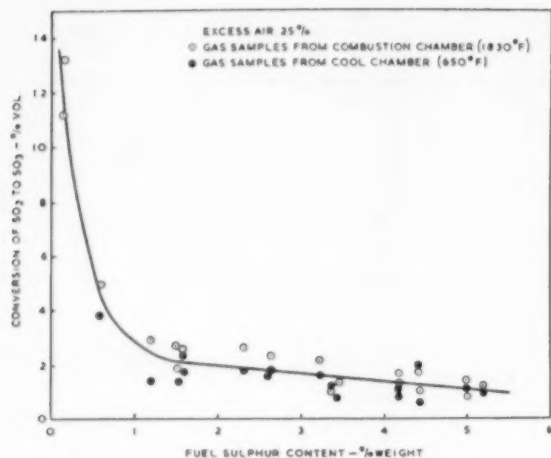


Fig. 6—Experimental furnace—variation in per cent conversion of  $\text{SO}_2$  to  $\text{SO}_3$  with sulfur content of fuel

temperatures in the air heater region of boiler plant. Data on the catalytic activity of finely divided ferric oxide have been given by Tolley (17), who stated that 1.5 per cent conversion could occur at 570 F.

However, examination of the data in Table VI shows that no significant change in  $\text{SO}_3$  content occurred across the air heater of the marine type boiler. To reconcile this with the observed increase in rates of corrosion and acid deposition, it is necessary to consider the equilibrium governing the association of  $\text{SO}_3$  with water vapor to form sulfuric acid vapor:



The gas temperatures at the air heater inlet and outlet were 720 F and 400 F respectively and for gases contain-

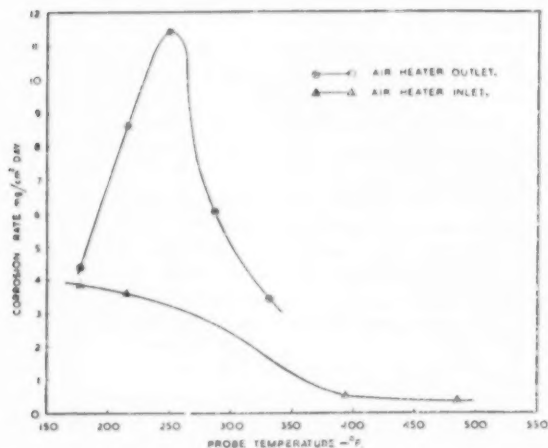


Fig. 8—Corrosion probe test installation "C" (marine-type boiler)—No additives

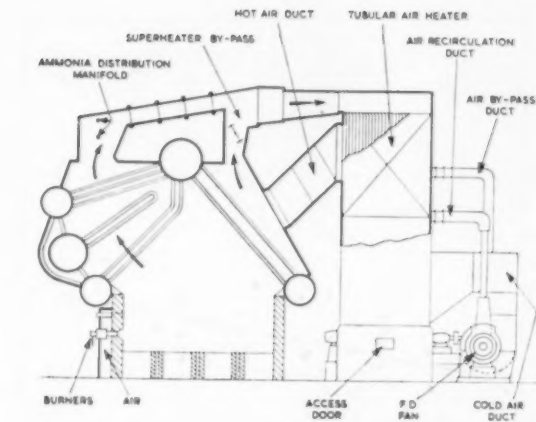


Fig. 7—Simplified sectional elevation of marine-type boiler, installation "C"  
This is an 85,000 lb per hr unit

ing 10 per cent water vapor the corresponding degrees of association are 2 per cent and 95 per cent (18). When the gases come into contact with cooled surfaces at the air heater inlet the largely unassociated  $\text{SO}_3$  molecules cannot condense to form sulfuric acid until combination with water vapor has taken place. The rate of condensation and subsequent corrosion would therefore be lower than when association to acid is almost complete, as at the air heater outlet. The chemical method does not distinguish between  $\text{SO}_3$  and  $\text{H}_2\text{SO}_4$  and is independent of the degree of association.

#### Operational Methods of Corrosion Control

##### EFFECT OF COMBUSTION CONDITIONS AND LOAD

Both the combustion (1) and catalytic (2) theories of  $\text{SO}_2$  oxidation stress the importance of minimizing

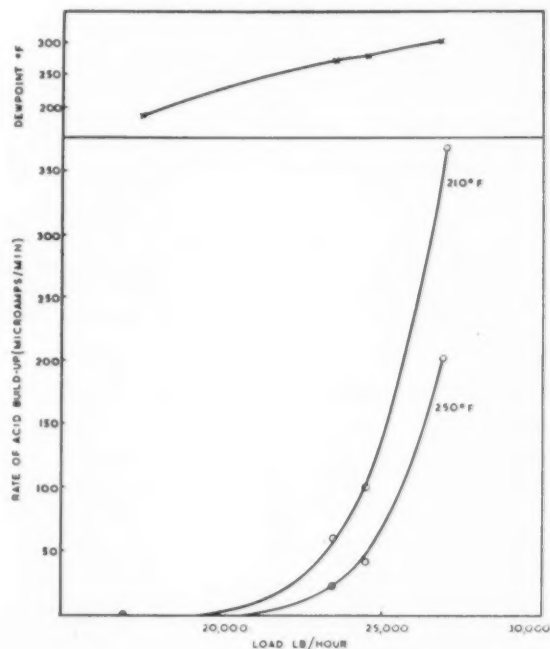


Fig. 9—Effect of load on dewpoint and rate of acid build up

SO<sub>2</sub> formation by operation with minimum excess air, and there is a wealth of information available on this factor. One of the most outstanding applications of the effect of combustion control on corrosion has been described by Lees (19). Air heater corrosion on 350,000 lb/hr oil-fired units was reduced several times when changes in plant design and operation enabled excess air to be reduced from 50 per cent to less than 20 per cent without smoke production.

High flame and metal temperatures, such as occur with flame impingement, are conducive to SO<sub>2</sub> formation and increase in SO<sub>2</sub> content with increasing temperature has been observed repeatedly on small and large installations (12). In small boilers with water cooled combustion chambers the cooling effect on the flame is such that little SO<sub>2</sub> would be expected and experience has shown that on many such appliances low acid dewpoints and rates of build-up obtain.

Operation of boilers at above design rating can accelerate the rate of formation of SO<sub>2</sub> by virtue of the increased flame temperature. Conversely, at low load SO<sub>2</sub> formation is reduced. No general relation between load and acid production has been established but a typical example is illustrated in Fig. 9.

#### USE OF ADEQUATE CLEANING METHODS

Deposits on air heater and economizer tubes not only reduce heat transfer but may catalyze (20) the formation of corrosive acid.

If blockage and corrosion are to be minimized by the maintenance of clean surfaces efficient cleaning methods such as water washing must be adopted. Water washing can be very effective provided that adequate distribution is secured and that large quantities of water are employed in a short time.

As an initial step in combating serious blockage difficulties, water washing was installed on the 100,000 lb/hr boiler illustrated in Fig. 14. Water was introduced through evenly distributed nozzles sited at the air heater exit, each nozzle discharging 300 IG/hr over an area of 3-4 square feet. Washing was carried out at regular intervals of 350 hours for a period of one hour with the boiler off load. From analyses of tube deposits it was estimated that air heater tube life would be increased from two years to seven.

#### Control by the Use of Additives

##### GENERAL

Most of the successful additives used depend for their action on chemical combination with the SO<sub>2</sub> in the flue gases, although a recent development has been in the application of inhibitors of metal corrosion by condensed acid (21). The preferred method of addition will depend on whether the additive is solid, liquid or gaseous. For solid additives, the following methods have been used:

- (a) solution in oil feed (if soluble in oil)
- (b) transport by secondary air into combustion chamber.
- (c) injection as suspension in oil into fuel oil feed line.

Liquid additives may be dispersed in the oil if miscible, injected into the oil feed line or sprayed into the flue gases.

For gaseous additives, the problem is to distribute uniformly a small quantity of gas into a very large volume of flue gas. The use of distributors having open orifices is not often suitable, as the variable external pressure due to the flue gases can affect the very small flow of additive quite severely. A method of flow restriction is required which will increase the manifold pressure of the gas. The use of low-porosity, sintered disks has proved to be effective for this purpose.

For larger installations, a preferable method of distribution for gaseous additives is to dilute the gas at a ratio of at least 10:1 with air or with flue gas and to distribute the diluted gas by means of a manifold system with open orifices. In this case the flow of gas at each orifice is larger, and greater momentum is available for mixing.

##### SOLID ADDITIVES

A variety of solid materials has been used, with varying success, to prevent low temperature corrosion in oil-fired boilers. It is important, however, that the addition of such materials should not adversely affect the operation of other regions of the boiler, such as the superheaters. For neutralizing the SO<sub>2</sub> in the flue gases, compounds of the alkali metals (sodium, potassium) which break down to give the oxides in the flame zone would probably be suitable materials if it were not for their property of forming low melting point sulfates, which can produce bonded deposits on superheater tubes. Some members of the alkaline-earth metals (magnesium, zinc), however, have the necessary basic properties and yet do not form low melting point compounds which affect superheaters. Magnesium oxide and carbonate, zinc oxide and zinc metal powder have been used as additives against low temperature corrosion in small oil-fired rigs and in commercial plant (22, 23), and dolomite, the double carbonate of magnesium and calcium, has also been used extensively (24, 25). The main drawbacks to the use of these materials are the difficulty of distributing them uniformly and the formation of products at their surface which impede further reaction. Frequently it is necessary to use quantities of solid additives in excess of the stoichiometric amount and the injection of these large quantities can produce rapid fouling. Information on the rate of fouling induced by dolomite injection has been provided in Part I of this paper. A comprehensive account of trials in the UK and Europe to assess different additives has been provided recently by Jarvis (15).

##### LIQUID ADDITIVES

Little information is available on the use of liquid additives mixed with fuel oil or injected into the feed line. Trials have been made (15) with heterocyclic tertiary amines sprayed into flue gases for corrosion inhibition purposes. In general, these are injected where the flue gas temperature is between 390 F and 570 F.

##### GASEOUS ADDITIVES

Ammonia is the only gaseous additive which has been applied commercially. The results of the original research work on the use of anhydrous ammonia for the prevention of low temperature corrosion have been given elsewhere (13).

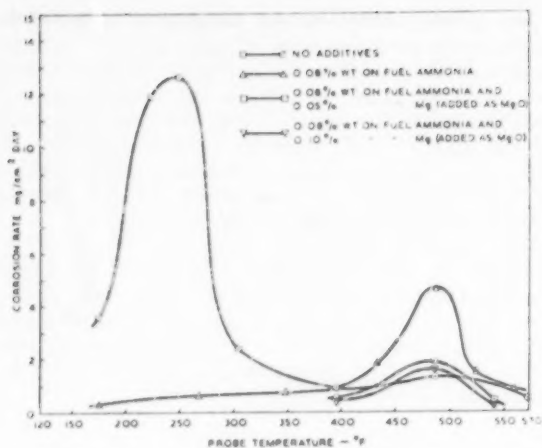
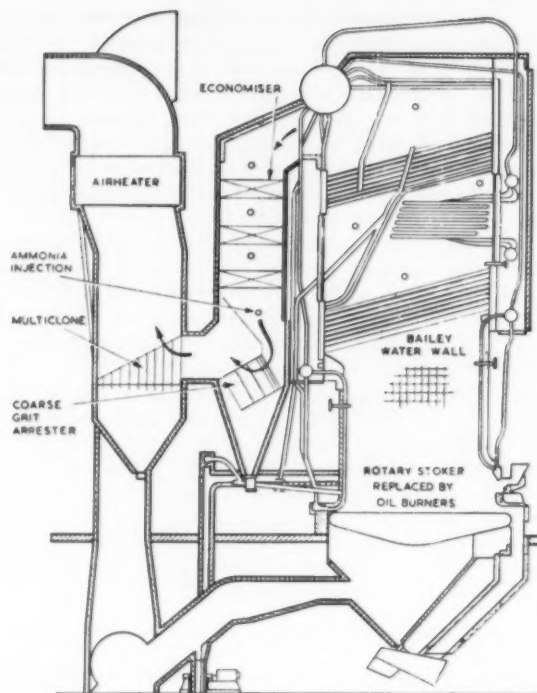


Fig. 10—Corrosion probe tests on experimental furnace

Fig. 11—Simplified sectional elevation of boiler with rotary air heater, installation "A"



The main advantages of ammonia, compared with the solid additives mentioned above, are its rapid diffusion and reaction which permit quantities little in excess of the stoichiometric amount to be used, in contrast with the considerable excess over stoichiometric required with the solid additives, owing to their comparatively low contacting efficiency.

The protective action of ammonia when injected into flue gases depends on the formation of ammonium sulfate. The reaction takes place in two stages, first, the formation of ammonium bisulfate by a gas phase process between  $\text{NH}_3$  and  $\text{H}_2\text{SO}_4$ , and second, the conversion of bisulfate to ammonium sulfate by a surface reaction with  $\text{NH}_3$ .

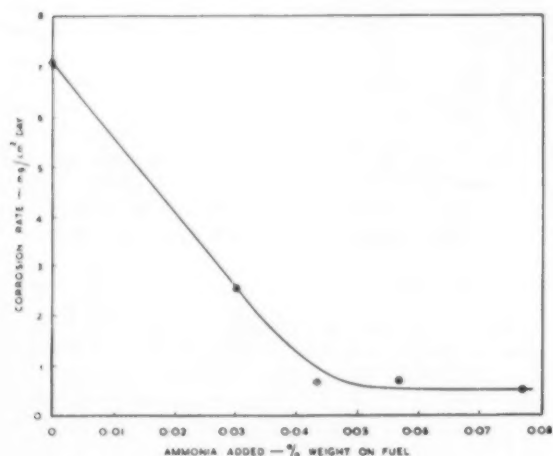
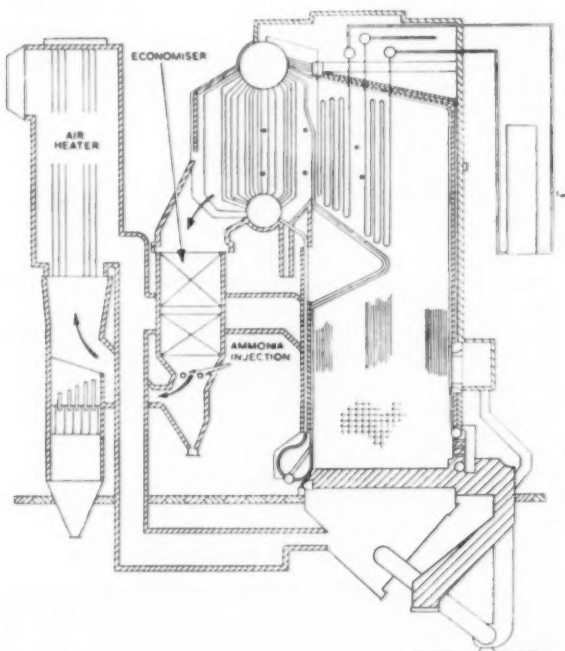


Fig. 12—Corrosion tests on installation "A"

Fig. 13—Simplified sectional elevation of boiler with tubular air heater, installation "A"





The success of the process depends to a large extent on the correct selection of the entry point for the ammonia. If the temperature is too high, a proportion of the ammonia will dissociate, while if the temperature is too low, ammonia may be taken up by the  $\text{SO}_2$  in the flue gases with the formation of ammonium sulfite and bisulfite. On the basis of the original laboratory work, it was recommended that injection be made in the temperature range 390–660 F.

The distance of the entry point upstream of the surfaces it is desired to protect, must also be as large as is consistent with temperature considerations and plant lay-out, in order to give the longest possible contact time and hence to ensure the most efficient reaction.

Above about 400 F ammonium bisulfate exists in the liquid form and the presence of molten films on metal surfaces above 400 F entails a risk of slight corrosion.

Further laboratory work has been carried out on the small refractory-lined furnace (Fig. 5) to determine the extent and severity of corrosion by bisulfate. The degree of corrosion was determined by means of a corrosion probe at temperatures in the range 284–572 F for three levels of ammonia concentration. The results of these tests are given in Fig. 10 from which it is seen that for 0.08 per cent by weight of fuel of ammonia, the corrosion due to the action of molten ammonium bisulfate reaches a small peak at a temperature of 482 F. Total corrosion, as measured by the area under the peak, was approximately 15 per cent of that measured with no ammonia injection at temperatures below the acid dewpoint.

Many industrial boilers operating at relatively low steam temperatures and pressures have air heater or economizer temperatures below 482 F, but for larger, high efficiency plants, the metal temperatures in these will probably be in this region. Although the corrosion risk is not serious, sticky deposits of ammonium bisulfate and ash may be formed and difficulties due to this cause have been described (5).

Accordingly, the laboratory researches have been extended to investigate the possibility of eliminating the effects of ammonium bisulfate deposits at high metal temperatures, by the use of a second additive in very small concentrations. The injection of magnesium oxide (0.05 per cent weight magnesium on fuel) into the combustion chamber reduced considerably the small peak in the corrosion curve due to ammonium bisulfate deposits and deposits were dry and easily removable. The corrosion curves obtained are shown in Fig. 10. A variety of other supplementary materials is being assessed.

#### Full Scale Trials on Ammonia Injection

##### INSTALLATION "A"

Exploratory trials were carried out on a boiler of 150,000 lb/hr evaporation fitted with an economizer and a rotary air heater (Fig. 11). Rapid corrosion of air heater elements had been experienced, in spite of raising the exit gas temperature to 330–340 F by cold air bypassing, and various powdered additives had been tried with little success. Ammonia was added between the economizer and air heater by means of a distributor pipe running the full width of the boiler and drilled with  $1/32$  in. holes at 1 foot spacing. The corrosion was assessed by exposing 28 gage mild steel test plates, of about 24 sq. in. exposed area, at the top of the rotary preheater elements

and determining the loss of weight after 6 hour periods. The results of the tests are given in Fig. 12, which shows that the corrosion was reduced to a very low level by the addition of 0.05 per cent by weight of ammonia on fuel. This boiler was subsequently converted back to coal firing, so that no long term trial was possible, but another boiler (Fig. 13), of the same evaporative capacity but fitted with a tubular air heater, was equipped for ammonia injection at the same installation. Ammonia was diluted with hot air from the FD fan at 1 volume ammonia to 10 volumes air and was passed into two 3 in. pipes, drilled with  $3/16$  in. holes, running across the gas path between the economizer and air heater. The concentration of ammonia used was 0.06 per cent by weight on the fuel flow, and this proportion was maintained irrespective of variations in boiler load by means of a proportioning controller in the steam offtake line. The air heater tubes were cleaned at two-week intervals by air lancing; the deposits were removed very easily. The exit gas temperature was reduced from 340 F–300 F, representing a gain in efficiency of 1.3 per cent, and after running for eight months, the boiler was taken out of service for annual survey. No evidence of corrosion was found in the air heater tubes, which were clean and bright after water washing; the original tool-marks could still be plainly seen inside the tubes.

Another boiler has now been fitted with ammonia injection equipment at this installation.

##### INSTALLATION "B"

Severe air heater corrosion had been experienced on a La Mont boiler of 100,000 lb/hr maximum capacity, necessitating a complete overhaul and extensive tube replacements every two years. The boiler is representative of a widespread and popular class, which is used extensively in industry, especially in Europe. A diagram is given in Fig. 14. The ammonia injection manifold was fitted between the second and third banks of

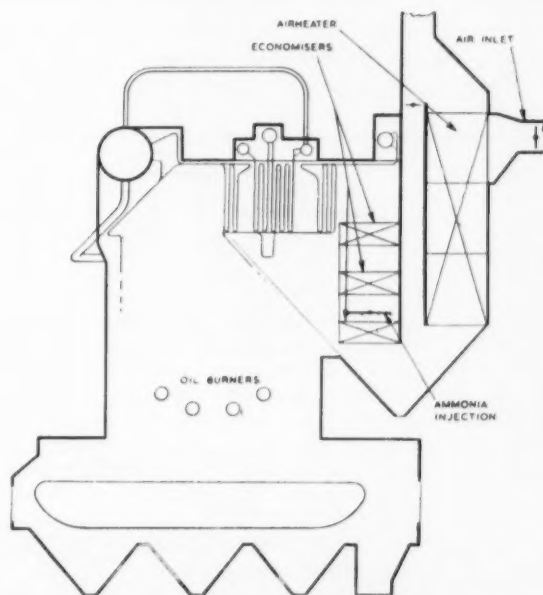


Fig. 14—Simplified sectional elevation of La Mont boiler, installation "B"

economizer tubes, where the gas temperature was approximately 620 F. No corrosion had been experienced in the lower tube bank, but injection in this zone enabled good mixing to be achieved before the gases entered the air heater tubes. The distributor used was of the type employing sintered, stainless steel disks as flow restrictions and consisted of a central tube to which several side tubes were fitted carrying sintered disks at their extremities. The nozzles were spaced so that good coverage of the economizer cross section was obtained. In order to remove quickly and efficiently the soluble deposits of ammonium salts, which slowly build up on the tube surfaces, water washing equipment was installed for the air heater and economizer.

The boiler was run for approximately 400 hours without the injection of ammonia. A number of selected air heater tubes was then scraped over a given area, using a similar technique to that described by Lees (26), and the iron contents of the scrapings were determined. From these results the wastage rates of the tubes were calculated. The tubes were water washed to remove deposits and a similar trial was made using an ammonia injection rate of  $4\frac{1}{2}$  lb/hr or 0.08 per cent by weight on fuel. The results are given in Table VIII.

From the results to date it is estimated that the life of the tubes would be increased to about 7 years by the use of water washing and with ammonia injection to about 18 years.

#### INSTALLATION "C"

A series of trials was carried out on the marine-type, water-tube boiler, previously illustrated in Fig. 7. Originally, the ammonia injection point was positioned about 2 feet from the air heater inlet, but experience showed that poor distribution resulted, owing to the short mixing time available to the flue gases before entering the air heater tubes. The distributor was moved back beyond the superheater bypass to the end of the horizontal duct; ammonia distribution was then satisfactory owing to the longer contact time avail-

TABLE VIII—WASTAGE RATES OF AIR HEATER TUBES FROM INSTALLATION "B" WITH AND WITHOUT AMMONIA INJECTION

Tube No.	Wastage Rate, $10^{-3}$ Inch per 100 Hours	
	Water Washing No Ammonia	Water Washing 0.08% Wt. Ammonia on Fuel
1	1.2	0.8
2	0.4	0.4
3	4.3	1.2
4	4.0	1.6
5	4.0	0.8
6	0.4	0.4
7	0.4	0.4
8	0.8	0.4
Mean	1.9	0.75

able. The distribution system used was of the type employing sinters as flow restrictions.

The results of corrosion probe tests at the air heater inlet and outlet are shown in Figs. 15 and 16. Comparison with the curves in Fig. 10 show that the injection of ammonia at the rate of 0.05 per cent by weight of fuel reduced corrosion very considerably at temperatures below the acid dewpoint of untreated flue gas. Slight ammonium bisulfate corrosion occurred when the probe was maintained above 400 F at the air heater inlet. However, the metal temperature at the hot end of the air heater is below this level and no bisulfate attack would be expected. This was confirmed when the boiler, which is normally used only for peak load demands, was operated at full load for 500 hours with ammonia injection. Examination of the air heater tubes showed no signs of bisulfate attack and the deposits were dry. Over the 500 hour run the pressure drop across the air heater had increased 20 per cent.

#### Acknowledgments

The authors wish to express their thanks to the Chairman and Directors of the British Petroleum Company for permission to publish this paper, and to the Royal Board of Waterfalls (Sweden), A.K.U. Company (Holland), the Electricity Trust of South Australia, the Superheater Company and to the United Kingdom Central Electricity Generating Board for cooperation in pilot scale and plant investigations.

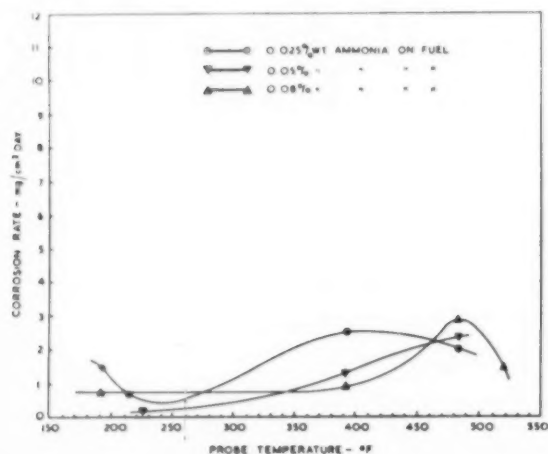


Fig. 15—Corrosion probe tests at air heater inlet on installation "C" (marine type boiler)

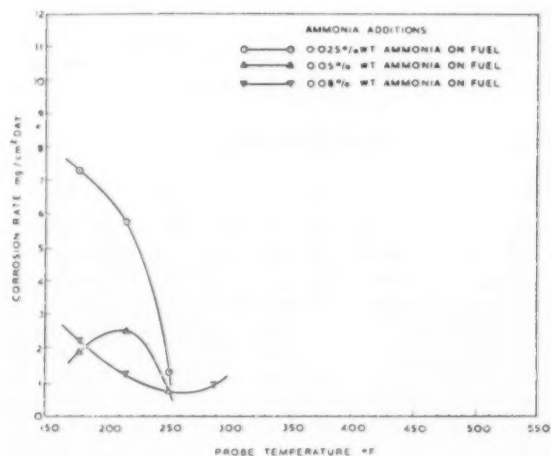


Fig. 16—Corrosion probe tests at air heater outlet on installation "C" (marine type boiler)

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## Appendix I

### CHEMICAL DESCALING METHOD

The steps involved in the descaling process were as follows:

1. Boil for an hour in a solution of: 30 per cent by weight sodium hydroxide, 2 per cent by weight potassium permanganate, 68 per cent by weight water.
2. Wash under water and scrape with a wire brush.
3. Immerse for two minutes in a solution at 60 C of:

25 per cent commercial concentrated nitric acid  
5 per cent 20/100 hydrogen peroxide, 70 per cent water.

4. Again wash and scrub with a wire brush or apply greater mechanical abrasion.
5. Where necessary steps 1-4 repeated.

In all cases, blank tests were carried out with uncorroded test pieces to determine the loss of metal due solely to this process, and a correction was applied to the corrosion calculations.

## Appendix II

### METALLOGRAPHIC EXAMINATION OF HEAT RESISTING ALLOYS

*Specimen No. 1—20 Per Cent Chromium, 7.2 Per Cent Nickel*

Metallographic examination at  $\times 100$  magnification of a polished section of this material showed a general attack to have occurred with some shallow pitting. At  $\times 300$  magnification, however, intergranular attack was revealing. Etching with a reagent for showing the general microstructure revealed a second grain boundary phase which probably was (or had been) ferrite. Little reaction was experienced with a reagent which attacks ferrite, but etching with alkaline permanganate, which attacks sigma-phase, suggested that these areas were largely composed of this latter phase, probably formed by

decomposition of the ferrite (sigma-phase is an inter-metallic compound of approximately equal parts of iron and chromium, with a low corrosion resistance). This is consistent with the experimental conditions, since the alloy was heated for a considerable time in the critical temperature range for sigma-phase formation (ca 900-1700 F). It is conceivable that much carbide precipitation occurred during the experiment, and this would denude the surrounding areas of chromium, thereby reducing the corrosion resistance of the chromium starved material. However, the attack took place on the second phase, and the formation of sigma-phase is therefore the more likely reason for the intergranular attack.

*Specimen No. 2—25.9 Per Cent Chromium, 18.5 Per Cent Nickel*

As with specimen No. 1, etching with a general reagent revealed a second phase mainly located at the austenite grain boundaries. Corrosion was confined almost entirely to this sigma-phase. Some reaction also occurred with Murakami's reagent, denoting the presence of carbides in the microstructure.

The formation of sigma-phase and the precipitation of carbides are normal for this type of steel when operated in the temperature range 1112–1472 F.

The formation of the sigma-phase would be particularly favored in this case by the relatively high silicon content of the material. The same conclusion may be drawn, therefore, as for specimen No. 1, that is, that intergranular attack took place on the sigma-phase, although the corrosion was much heavier.

*Specimen No. 3—11.9 per cent Chromium, 59.5 Per Cent Nickel*

The microstructure consisted of austenite with heavy grain and grain boundary precipitates, those near the outside edges of the specimen being agglomerated into large gray areas. A certain amount of agglomeration had also taken place at the grain boundaries. It was on this precipitated phase that the corrosion occurred.

Heavy carbide precipitation is likely to occur in this alloy if it is heated for prolonged periods at high temperatures, and it is thought that much of the precipitation, particularly within the austenite grains, is carbide. No mention is made in the limited literature available of the occurrence of sigma-phase in this type of alloy, and it is not known whether sigma can occur, but it is unlikely, owing to the absence of delta-ferrite and the stability of the austenite. Nevertheless, etching with

alkaline permanganate produces heavy attack on the large gray areas and on the grain boundary agglomerates, suggesting the presence of sigma-phase.

*Specimen No. 4—25.2 Per Cent Chromium, 12.7 Per Cent Nickel*

The appearance of the descaled specimens (Fig. 3) suggests that the corrosion suffered by this material was similar to that of specimen No. 2 but more widespread. Metallographic examination showed that the pattern was the same as for specimens Nos. 1 and 2, with the corrosion following a second grain boundary phase which was etched by alkaline permanganate.

The composition of this alloy is critical, since the range of nickel and chromium contents lies at the junction of the alpha plus sigma, the gamma and the gamma plus sigma regions of the Fe-Cr-Ni system at 1650 F. If a stable austenite alloy is required, a careful balance must be maintained between the ferrite-forming elements (such as Cr and Si) and the austenite-promoting elements (such as C, N and Ni). On the basis of its carbon, chromium and nickel contents alone this alloy should be asustenite, but this does not take the other elements or the precise operating temperature into account. In fact, the alloy was "out of balance" since sigma-phase was encountered at the grain boundaries, and this was responsible for the intergranular corrosion observed.

*Specimen No. 5—18.4 Per Cent Chromium, 53.3 Per Cent Nickel*

Although not quite as badly corroded as specimen No. 3 this alloy suffered deep intergranular penetration. The microstructure and corrosion mechanisms are similar to those for specimen No. 3.

## **Compendium of Water Pollution Laws**

Publication of a compendium of state and federal water pollution abatement laws of the United States was announced today by the Manufacturing Chemists' Association.

The fifty-three chapters of the compendium cover the laws of the fifty states, federal laws and those of the District of Columbia and Puerto Rico pertaining to water pollution.

One chapter is devoted to each state or jurisdiction. It describes the organization of the water pollution control commission or agency and gives its address; describes the commission's water pollution abatement policy, gives a résumé of the law and briefly outlines the rules and regulations in force.

Credit for preparation of the book published by MCA's Water Pollution Abatement Committee is given to Carl E. Geuther, of the Legal Department, E. I. du Pont de Nemours & Co., Inc.

In the preface Mr. Geuther points out that the purpose of the compilation is to provide a handbook for reasonably easy reference. It is planned to keep the work up to date by the issuance of biannual supplements which correspond generally to state legislative sessions.

Copies of Manual W-5—Compendium of Water Pollution Laws—are available at \$5 each from the Manufacturing Chemists' Association, Inc., 1825 Connecticut Ave., N. W., Washington 9, D. C.

## **Reliance Gauge 75th Anniversary**

The Reliance Gauge Column Company, Cleveland, Ohio, has been celebrating its seventy-fifth year during 1959. Continuously since 1884, this company has produced water columns, water level gages and other equipment designed to aid steam power plant operators in keeping a safe check on water levels in boilers and other vessels.

The first patent was issued on the "Alarm" Water Column to Cleveland inventors, Frank Bort and Jackson Allen, on October 7, 1884. The original company, known as "Reliance Gauge Co." operated until 1910 when new owners incorporated under the present name.

Through the years, Reliance developed ever-improving types of floats, gage valves, gage (or "try") cocks, and gage inserts which were found necessary when pressures exceeded the safety factor for tubular glass. Precision-made forged steel bodies with efficient finger-type and solid plate clamping for both prismatic and mica-protected flat glass became the standard for higher pressure gages. An all mica window was introduced for high pressure use, to resist the erosion common to glass, and the effects of most chemicals.

Visibility of gages became a problem as boilers grew in size—particularly in height—and Reliance introduced gage illumination, vision-focusing hoods, and reflector-type or "periscope" hoods to throw gage images downward to a floor-stand mirror on the operating floor.



By IGOR J. KARASSIK\*

Worthington Corp.

## Steam Power Plant Clinic—Part X

### QUESTION

We would like to ask your opinion relative to the safety of our projected feedwater suction arrangement from the point of view of the transient conditions incidental to sudden load drops. We will be installing a 300,000 kw unit which will be served by three so-called one-third capacity boiler feed pumps without a spare. Each pump is rated to handle 820,000 lb/hr of feedwater coming from a deaerating heater. At the maximum load of 305,550 kw, the following conditions will prevail:

Flow to the boiler.....	2,122,000 lb/hr
Heater pressure.....	83.1 psia
Feedwater temperature.....	314.7 F
Feedwater enthalpy.....	284.8 Btu/lb

The heater pressure will be prevented from falling below the atmospheric pressure by means of auxiliary steam admission at light loads through a pressure reducing valve, set to maintain a minimum heater pressure of 20 psia. At the minimum flow of 350,000 lb/hr to the boiler, the condensate delivered to the heater will have a temperature of approximately 170 F and an enthalpy of 138 Btu/lb.

The deaerator storage tank, which is 11 ft 6 in. in diameter by approximately 46 ft 6 in. in length, will have a maximum storage level of 5 ft 3 in. above the centerline of the tank, at which level it will hold 32,700 gallons of feedwater. At the minimum expected level of 1 ft 9 in. above the centerline, the storage will be 22,700 gallons. Should the storage level fall below this minimum, a transfer pump will deliver cold condensate from a separate makeup tank to the heater.

You will see from the attached schematic drawing, Fig. 1, of the suction piping that the main suction header is 24 in. piping, branching out to the three boiler feed pumps with 12-in. lines. The volume from the storage tank outlet to the branching out of the connections and the volume of the individual lines to the pumps is shown on the drawing.

Based on this information, could you advise us whether

The boiler feed pump and its associated equipment represent a major operating and maintenance consideration in today's power plant. Here we run in question and answer form a series of clinic sessions on various boiler feed pump problems. The replies are the work of one of the topmost pump authorities and give specific information which we hope will prove valuable to our readers.

the arrangement will be safe against possible difficulties from transient conditions following a trip-out of the unit?

### ANSWER

The analysis of the effects of sudden load drops on the performance of boiler feed pumps operating in open feedwater cycles has been presented in the paper "Centrifugal Boiler Feed Pumps Under Transient Operating Conditions"<sup>1</sup> to which I refer you for a complete treatment of the subject. This paper outlined a method of comparing the predicted *actual* rate of heater pressure decay per unit of volume of feedwater pumped to the *allowable* rate of pressure decay. Operation of the boiler feed pumps at flows in excess of those at which the *actual* rate exceeded the *allowable* rate would lead to flashing of feedwater in the feed pumps and cause serious difficulties. Means were indicated to establish the values of these *actual* and *allowable* rates of pressure decay.

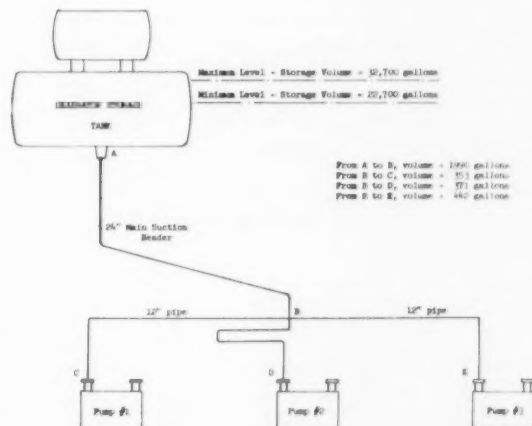
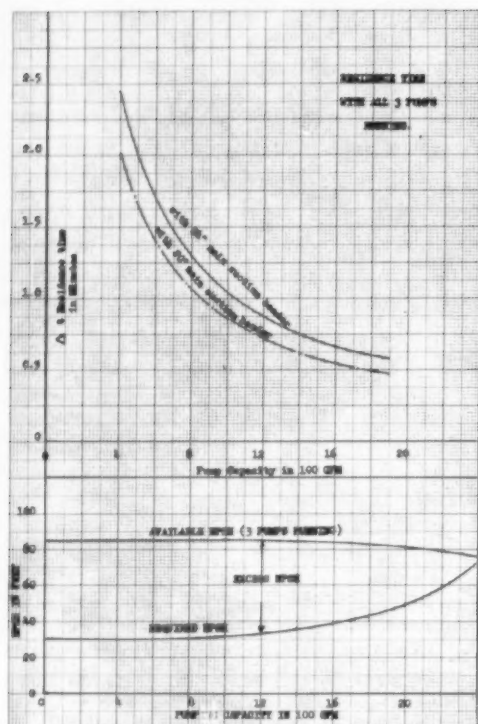


Fig. 1—Schematic drawing of a suction piping arrangement whose safety under transient conditions from sudden load drops is analyzed and precautions suggested

\* Consulting Engineer and Manager of Planning, Harrison Div.

<sup>1</sup> ASME Paper 53-P-32, by I. J. Karassik, G. H. Bosworth and W. D. Elston, presented at the Fall Meeting, Rochester, N. Y. October 5-7, 1953.



**Editor's Note:** Since the inception of this series a number of inquiries have been made on the individual Clinic problems discussed by Mr. Karassik. Recently readers have asked if they can present problems of their own to Mr. Karassik for his comments. These, the author assures us, are most welcome. He will answer readers directly and we shall publish these answers as quickly as our schedule permits.

Fig. 2—Curve of available and required NPSH conditions with residence time for the No. 3 pump of Fig. 1 superimposed to permit analysis of the system

As far as the *allowable* rate was concerned, it was stated that following a sudden load drop, the feedwater in the suction piping took a certain time to void this piping before the colder feedwater from the heater could reach the boiler feed pumps. This time lag, called the "residence time" is equal to the volume of the suction piping in inches divided by the feedwater flow rate in gpm. The *allowable* rate of pressure decay is equal to the excess NPSH (the difference between the available and required NPSH) divided by the residence time. If we want to find the *allowable* rate of pressure decay in terms of units of volume pumped, we divide the rate in feet per minute by flow rate.

Table I shows the calculations for the allowable rate of pressure decay for flows to the boiler from 600 to 5700 gpm. It has been assumed that the balancing device flow, or leak-off, is 50 gpm per pump and that it is returned to the deaerating heater. Thus, with three pumps running, the flow in the suction piping exceeds the flow to the boiler by 150 gpm.

I have shown on your curve of available and required NPSH, Fig. 2, the magnitude of the excess NPSH. I have also superimposed on the same curve the "residence

time  $t''$  in the suction piping for pump No. 3 which has the greatest suction piping volume.

As an example of these calculations, take a flow of 3000 gpm to the boiler. The flow through the pumps, including the balancing device leak-off will be 3150 gpm. The residence in the common suction piping will be the volume in gallons contained in the 24-in. pipe from points A to B, Fig. 1, divided by the flow rate, viz:  $1990 \div 3150$  or 0.63 minutes. Pump No. 3 will have a flow of 1050 gpm through the 442 gallons (equivalent volume from B to E, Fig. 1.) of its own suction piping and the residence time therein will be  $442 \div 1050$  or 0.42 minutes. The total residence time from heater outlet to the suction of pump No. 3 will be  $0.63 + 0.42$ , or 1.05 minutes.

At 1000 gpm net pump flow, the available NPSH, Fig. 2, is 85 ft and the required NPSH is 32 ft., so that the excess NPSH is 53 ft. The allowable rate of decay will then be  $53 \div 1.05$  or 50.5 feet per minute. Dividing this by the flow from the heater (3150 gpm as above and expressing our decay rates in terms of 100 gallons pumped), the allowable rate of pressure decay will be  $50.5 \div 31.5$  or 1.60 feet per 100 gallons pumped. These calculations can be repeated for the entire range of flows.

TABLE I—ANALYSIS OF ALLOWABLE PRESSURE DECAY RATE

Feedwater Flow $dq/dt$ in GPM			Residence Time, $t$ in Min		NPSH in Ft		Allowable Decay Rate	
Total to Boiler	Through 3 Pumps	Per Pump	In Common Pipe	In Line to Pump No. 3	Available	Required	Available Excess	In Ft/Min, $dp/dt$
								In Ft/100 Gal. Pumped, $dp/dq$
600	750	250	2.66	1.77	85.0	30.0	55.0	12.4
1200	1350	450	1.47	0.98	85.0	30.0	55.0	22.4
1800	1950	650	1.02	0.68	85.0	30.0	55.0	32.4
2400	2550	850	0.78	0.52	85.0	30.5	54.5	41.9
3000	3150	1050	0.63	0.42	85.0	32.0	53.0	50.5
3600	3750	1250	0.53	0.35	84.5	33.5	51.0	58.0
4200	4350	1450	0.46	0.30	84.3	36.0	48.3	63.5
4800	4950	1650	0.40	0.27	84.0	39.0	45.0	67.2
5400	5550	1850	0.36	0.24	83.0	43.0	40.0	66.7
5700	5850	1950	0.34	0.23	82.0	46.0	36.0	63.0

The ASME paper referred to above showed that the *actual* decay rate, if expressed in terms of units of volume pumped out of the heater, was independent of the feedwater flow rate and could be calculated from the following relation:

$$\frac{dh_z}{d_q} = - \frac{(h_{z0} - h_{c2})}{Q_h/100}$$

where:

$\frac{dh_z}{d_q}$  = actual decay rate in Btu per 100 gallons pumped  
 $h_{z0}$  = enthalpy in heater at initial load  
 $h_{c2}$  = enthalpy of condensate at final load

In this particular case, we have been given a value of  $h_{z0} = 284.8$  Btu and  $h_{c2} = 138$  Btu. We can now calculate the actual decay rates for both the maximum and the minimum levels in the heater storage tank.

Level	$dh_z/d_q$ in Btu/100 gal	$dp/d_q$ in ft/100 gal
Maximum	-0.448	-1.27
Minimum	-0.645	-1.80

These values have been plotted on Fig. 3, where they are superimposed over the curves of the *allowable* rates of pressure decay. It appears immediately that the installation is not safe against the detrimental effects of a sudden load drop, since the *allowable* rate of decay falls below the actual decay rate with minimum storage level at all flows to the boiler. It is only when the level is maintained at its maximum value that pumping to the boiler can take place at flows up to 5100 gpm (2,320,000 lb/hr) without flashing at the pumps.

It is true that following a sudden load drop, the steam flow will be reduced immediately and the feedwater flow will follow this drop almost instantaneously. However, shortly thereafter (in a matter of seconds), the action of the feedwater regulator responding to boiler shrinkage will make the feedwater flow bounce back up to some undetermined new rate considerably in excess of the steam flow. Exactly what this new rate will be, I have no means to predict, since it will depend on the type of your feedwater controls and on their adjustment. Nevertheless, most installations that I have encountered experience a very appreciable so-called "bounce" in feedwater flow. It is therefore essential that it be possible to handle appreciable rates of flow after a sudden load drop without having the *actual* rate of decay exceed the *allowable* rate.

One means of improving the situation immediately comes to mind. The velocity in the common suction header can be increased without affecting the friction losses adversely in this particular case. If you were to use a 20-in. header instead of a 24-in. pipe, you would reduce the time lag in the common pipe by about 30

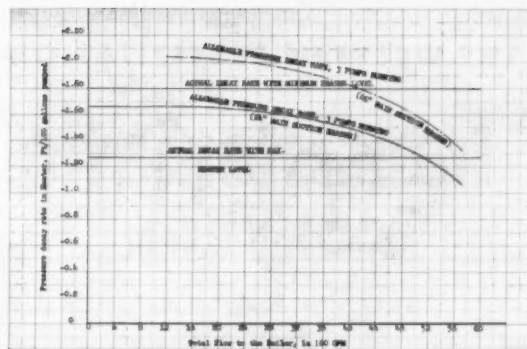


Fig. 3—Plotting the actual feedwater pressure decay rates against the allowable ones for the existing system of Fig. 1 and a suggested changed piping (20-in.) shows the problems a sudden load drop presents

per cent with a very beneficial effect on the *allowable* rate of decay. For instance, at a flow of 2400 gpm to the boiler, the residence time in the suction piping would be reduced from 1.30 to 1.06 minutes and the *allowable* decay rate from 1.64 to 2.01 feet per 100 gallons pumped out of the heater. The effect of the change from 24-in. to 20-in. piping has been indicated on Figs. 2 and 3.

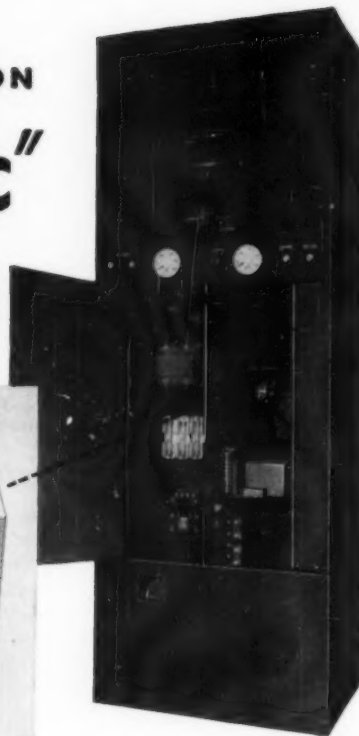
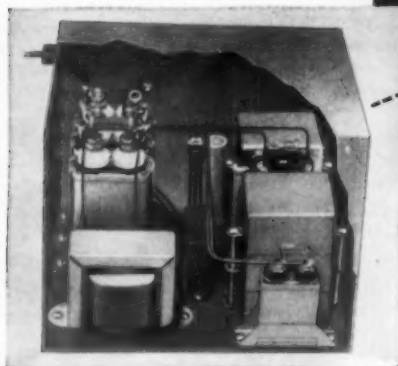
This may not necessarily be a fully sufficient margin of safety. You have mentioned that controls are provided to introduce cold makeup into the deaerator under low level conditions. Should this low storage level coincide with a unit trip-out, the *actual* pressure decay rate may be considerably aggravated by the sudden admission of an appreciable quantity of cold water into the heater. Note that the relation given above for the *actual* rate of decay was developed on the basis of the simplifying assumption that flow into and out of the heater balance even after a trip-out. If the cold water flow into the heater exceeds the flow out of the heater, the *actual* decay rate will exceed that given by the relation developed.

As a result, it may be wise to consider a second precautionary measure in the form of an "anti-flash" control. This is a control which is sensitive to a deficiency in available NPSH when compared to the required NPSH and which can be made to actuate a valve intended to admit auxiliary steam to the heater or cold water directly to the boiler feed pump suction. Either of these two actions are, of course, effective in reestablishing the necessary excess of available over required NPSH. You have stated that you already have a steam admission valve intended to prevent operation of the heater at below atmospheric pressure. The expenditure would therefore be limited to the control element only, since the valve to admit auxiliary steam is provided.

I repeat that the inclusion of such an "anti-flash" control may be a wise precaution, but the substitution of 20-in. pipe for 24-in. is a must.

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Water Treatment technology has advanced rapidly. But so too has boiler design. As a result many treatment advances are proved out on full scale operating boilers. This proving method opens many areas for honest differences of opinions on the technology involved and its application. Here is one such an area. It is one man's viewpoint and it is expected others will feel differently. COMBUSTION will gladly print any and all views submitted in the belief that open discussion leads to quicker understanding.

## Water Side Boiler Tube Failures—Their Origin and Treatment

Discussers: R. C. Ulmer,\* Combustion Engineering, Inc.  
J. C. McCabe†

JOE MCCABE

High pressure boiler installations have increased at a rapid rate during the past decade. Pressures of 2400 psi and higher are quite common. Most plants have operated with little or no boiler water problems. Yet we know that some plants have had and continue to have a lot of trouble, in many cases leading to tube failures. This warrants some investigation as to just why this happens to some and not to others. Dr.

Ulmer, we realize problems like this are not always clear cut and may involve several parties. You happen to have worked for the three parties concerned: that is, at present you are with a boiler manufacturer and formerly you worked with utilities and then, somewhat later with a water treating company. Could you consider this problem from all these standpoints? In the first place, why is there a problem?

DR. ULMER

You are starting off with the \$64 question and if its answer were known and agreed upon there would be no problem. Unfortunately each party you identify as concerned has a different perspective as to how and where the problem begins and lack of agreement results. The boiler manufacturer is sure his boiler is of satisfactory design and either questions water treatment or operating conditions. The boiler owner, having a part of the water treatment, has only boiler design to blame. The water treating company cannot contradict the

boiler owner who hires him so he also blames the boiler. As you know, the major boiler manufacturers have been forced to, in effect, operate water treatment departments to take care of these situations. Fortunately we have found that most boiler water treatment problems disappear when proper attention is given to operation and to water treatment. Yet before someone feels this is too quick and easy an answer let me clarify some points. May I suggest that we discuss the three points of view? They can be in any order you wish.

JOE MCCABE

Very well. Suppose we take the boiler owner first. What should be brought out in his respect?

DR. ULMER

I have always been intrigued with some speculation of the late Alex Dow of Detroit Edison Company, who

was one of those responsible for the success of the early power industry. He bemoaned the fact that little is actually known as to what takes place at the water-metal interface of a boiler tube at various heat transfer rates. Actually today we still mostly speculate, es-

\* Director of Research.  
† Editor, COMBUSTION.

pecially if some deposit is present. It is encouraging that the Joint Research Committee of the ASME has developed a program to study this phenomenon and especially to study limiting conditions involved in boiler tube failures.

The above should not be taken as an indication that boilers are designed on an unsound basis. As will be pointed out, years of operating experience verify present designs. Getting to the point, most plants are very carefully laid out from thermal and mechanical standpoints. This is not always true from the water standpoint. Actually it should be stressed that the boiler is only one part of the plant for which design must be considered. The condenser, and deaerator if used, heaters and the various numerous auxiliary pieces of

equipment all must be of such design as to furnish the boiler proper feedwater at all times, therefore, at partial load and start-up. Unfortunately, as many investigators have shown this is not always the case and much progress can be made by giving attention to items as:

1. Preventing introduction of undeaerated or partly deaerated condensate to the feedwater.
2. Making sure feedwater heaters do not operate under vacuum at times and draw in air.
3. Not adding heater drips directly to the condensate system.
4. Making sure evaporator vapor is properly "vented."
5. Making sure turbine gland seals do not add an appreciable amount of oxygen.

JOE McCABE

What about water purity?

DR. ULMER

You may be surprised to hear that excluding contamination, water purity is not much of a problem. Demineralizers and evaporators are available that supply quite satisfactory make-up. It is only when

excessive condenser leakage occurs or when pick-up of metallic oxides occurs that a water problem exists. Bypass demineralizers on the condensate or feedwater now are being considered to alleviate these conditions.

JOE McCABE

What about operating conditions?

DR. ULMER

Normal operation does not appear to be a problem with proper designs of preboiler systems. That is, when a proper feedwater is available. However, attention should be given to several items of an operating nature.

(1) *Initial cleaning.* Hundreds of pounds of oxide and debris usually is present in a boiler after erection. Proper alkaline cleaning followed by acid cleaning is preferred for removing this material. The acid cleaning should be done as near the operation date as possible so minimum rust will form. In any case, the boiler should be stored under slight pressure and filled with hydrazine treated water.

(2) *Storage when "idle."* This requires careful at-

tention and storage under nitrogen pressure filled with hydrazine treated water has been found to give good results.

(3) *Drawing procedure.* This requires careful attention. Various authors have covered very well the various precautions that should be taken to insure proper draining and protection from dust and dirt and corrosion even during annual inspections.

(4) *Condenser leakage.* This has been a problem in some of the older plants. Fortunately with recent advances in condenser design and means for detecting leakage this should not be much of a problem in present and future plants. Where leakage cannot be controlled the use of by-pass demineralizers may be considered.

JOE McCABE

What about the Fe and Cu controversy?

DR. ULMER

It is logical that these items should receive a lot of attention since deposits in modern boilers consist almost entirely of Fe and Cu. Many plants collect and weigh the metallic oxides in the boiler drum on draining. As much as several hundred pounds often is found and, of course, much more leaves the boiler with the water. Several thousand pounds may be removed by acid cleaning. Plants should investigate the source of these oxides. They usually originate in the preboiler system. If more than 0.02 ppm of the combined oxides is present in the feedwater, corrective steps should be taken to

eliminate them. These steps may range from plant design changes to raising pH of preboiler system, to use of filming amines, etc.

Mention also should be made of the fact that attention is being given the relative amounts of Fe and Cu that exist in deposits. There does not appear to be sufficient data available to offer much support to these findings. That is, either or a combination of both will cause trouble under certain conditions. Again the JRC work in ASME should aid greatly in clarifying the situation and in achieving uniform understanding.

JOE McCABE

That appears to cover the owners point of view pretty well, now what about the water treatment company?

DR. ULMER

There are a number of good water treating companies and all have the same general goal in mind. That is, to limit pickup of metallic oxides and to maintain overall satisfactory feedwater and boiler water conditions throughout the system. As we know, in many cases excellent results are obtained. However, there are some cases where satisfactory results do not obtain. These have previously been referred to and are plants

where some design or operating condition exists which treatment alone cannot cope with. It is natural for the water treating company to be loyal to the plant owner who hires him. The result is that the boiler is blamed even though it may be identical in design to one where the same water treating company's services is giving good results. This last statement, we know, may very well be challenged.

JOE McCABE

Is there any way this situation could be eliminated?

DR. ULMER

There is and it has proved itself. Reference is made to the plant checks made in certain cases where troubles persisted. Unfortunately as we well know such tests are time consuming, require trained personnel, and therefore are quite expensive. Therefore, the water treating company cannot afford to make many, if any, such checks. If such tests were carried out religiously we

are sure that design and operating conditions such as those referred to would be found. As mentioned our work has shown this to be the case and once "corrections" are made satisfactory results obtain. A corollary to this, of course, would be that if new plant designs took these matters into consideration there would be little if any water problems.

JOE McCABE

Do all the water treating companies recommend or use the same treatment?

DR. ULMER

No, they do not, even though essentially all high pressure boilers have the same make-up water and general design. Some prescribe alkalinities of 30 to 50 ppm in the boiler water. Considerable free caustic is present. Others prescribe lower alkalinities and still others the Coordinated pH-Phosphate Method. Also the use of volatile alkalis for pH control in condensate and feed-

water is far from standard. Some use neutralizing materials such as morpholine, cyclohexylamine or ammonia. Some use filming type amines. This is further complicated by the use of trade names which often do not indicate the material being used. Needless to say these conditions have not helped promote a clearer understanding of water treatment.

#### Boiler Manufacturer

JOE McCABE

Now finally what about the boiler manufacturer's point of view?

DR. ULMER

In most cases water problems have not been much of a problem and boilers continue to operate year after year without serious failures. This leads the boiler manufacturer to believe that if it is possible in most plants it should be possible in the remainder. This general opinion appears justified as there is little difference in design characteristics of boilers of about the same vintage.

Probably the chief difficulty that arises where problems occur is that deposits form on heat transfer surfaces. The boiler manufacturer allows for some deposits but there is a limit to the amount that can be considered

practical. Actually some boiler owners have expressed the opinion that boiler designs should be such that deposits can be present. Generally reference is made to the fact that circulation should be such when deposits are present that overheating and rupture of the tube will not result. Unfortunately as has been pointed out by many investigators rupture from overheating is not necessarily the most common type of failure. Rather, thinning of the tube from attack by concentrating boiler water salts in the deposit is the common type of failure. In such cases metal temperature may only be a few degrees over that which would exist when no

deposit is present. However, this is sufficient to cause concentrations of boiler water to several per cent strength and if free caustic is present rapid attack and possibly embrittlement of the tube can occur. Can the boiler manufacturer design so this will not happen? It might be possible to cut down heat transfer so deposits would not lead to overheating and rupture but

JOE McCABE

What then is the practical way to eliminate these troubles?

DR. ULMER

The "way" is clearly indicated by considering the mechanism of failure. As mentioned, deposits are necessary. A means must be found for elimination of the deposits or a water treatment must be used so that failures will not result if deposits do form. Although we as boiler manufacturers are not responsible for water

so much surface would be necessary that the boiler would be very costly. However, as pointed out, this is not the usual type of failure. Cutting down heat transfer rates would not necessarily help the common type of failure due to concentrating boiler water salts in deposits. As pointed out only a few degrees increase in metal temperature is necessary for this to occur.

JOE McCABE

What about preventing deposit formation?

DR. ULMER

Many articles have been written on this subject. The boiler feedwater system has been shown to very definitely be the source of metallic oxides that deposit in the boiler and lead to the failures referred to. The reasons for the pick-up of the oxides also have clearly been defined. Low pH and/or the presence of dissolved oxygen are the causes. Why then is it so difficult to control the pickup of oxides? It generally isn't at full load operation in most plants. Maintaining a pH of 8.8 to 9.2 and a slight excess of hydrazine in the entire condensate and feedwater system will suffice. But what about conditions when the units are out of service, or at start-up or at partial or low load? It is during these times that corrosion may take place leading to pickup of sufficient metallic oxides to cause deposits. Only by consideration of these conditions, both by proper design and operation can satisfactory

results be insured. These subjects have previously been referred to.

Although any deposits must be considered undesirable, some generally form during the life of the boiler. Generally they are confined to a small percentage of the water-side surface. Why do they form at one location and not at others? Certain factors such as inclination of tubes are obvious. For example, in arches, roof or floor tubes, there is more of a chance for deposits to settle out than in vertical tubes. This is true not only during operation, but also when the unit is being drained. However, the exact mechanism of deposit is not known. As mentioned the JRC of the ASME is planning to carryout an investigation of this subject during the next several years. Perhaps this program will supply answers that will make possible operating without deposits but this is questionable.

JOE McCABE

Assuming, therefore, that some deposits are to be expected, what can be done?

DR. ULMER

As mentioned, in modern high pressure boilers very seldom do sufficient deposits form to cause failure by overheating and rupture. Rather most failures result from concentration of the boiler water in the deposit and consequent attack by caustic present in the concentrate. An obvious method to eliminate this type of attack is to eliminate the caustic. This is possible by two general methods available in the industry today. The first involves the Coordinated pH-Phosphate Control and the second the use of so-called zero or volatile treatment.

The first or Coordinated pH-Phosphate Control consists of maintaining sufficient phosphate to prevent corrosion in the boiler. No free caustic is present. Therefore, if such boiler water concentrates in deposits, no caustic will be present to attack the metal beneath

the deposit. Excellent results are being obtained in many boilers with this type treatment today.

Typical control of the boiler water would be:

pH.....	10.0-10.5
PO <sub>4</sub> .....	10-30 ppm
OH.....	.0 or less than 2.0 ppm

The second, zero or volatile treatment, is rather new. It came about by considerations given to treatment for once-through systems. Detailed testing indicated that corrosion would not occur in such systems with practically no treatment, so consideration was given to the use of such a treatment in natural and controlled circulation boilers. Typical control of the boiler water would be:



pH ..... 8.5 to 9.5  
NH<sub>3</sub> added to feedwater to maintain pH 8.8 to 9.2  
N<sub>2</sub>H<sub>4</sub> added to feedwater (twice O<sub>2</sub> concentration)

No phosphate is used and only a trace of free caustic, if any, is present. Therefore, again there is no chance of sufficient caustic forming in deposits to lead to attack beneath the deposit. Excellent results are being obtained with this treatment in boilers today.

As no phosphate is used, the objection to this treatment is sometimes raised that difficulty may occur if condenser leakage occurs. In fact, it is pointed out that varying phosphate concentration serves as an indication that leakage is occurring. It is true that phosphate is desirable if leakage occurs. Some plants using the zero treatment have pumps available to add to it should leakage occur. However, plants on the zero treatment have no trouble telling when leakage occurs as the

electrical conductivity of the boiler water increases greatly. For example, in the absence of leakage these plants have a boiler water conductance of the order of 5 micromhos. Even a small leak will increase this several fold. When this occurs phosphate and other treatment, if desired, can be added until the leakage is stopped.

It is realized that plants not using these types of treatment are operating satisfactorily. However, should some of the operating conditions referred to obtain it is possible that troubles will occur. As is known, in many cases troubles do not arise until after several years of operation. It is probable that adverse conditions existed all the time. In most cases it is considered that some "recent condition" caused the trouble and a "cure" is looked for. As pointed out, experience has shown that good conditions can be insured by giving proper consideration to plant design and operation and by using a "preventative" type water treatment.

### ***Corrosion Research at the National Bureau of Standards***

Since metals were first used for industrial purposes, man has waged constant warfare against the forces of corrosion. This complex process has been defined as the destruction of a metal by chemical or electrochemical reactions with its environment; and deterioration often proceeds in direct proportion to the aggressiveness of the environment. Essentially, corrosion is process metallurgy in reverse. Iron, for example, occurs in nature generally as oxides or hydroxide, and is refined to the steels of structural use. When exposed to a corrosive environment, the metal tends to revert to these original forms, which are then called "rust."

As the corrosive process is influenced by many factors, a study of metals in their commercially usable state affords little information on the fundamental nature of the process. Such information can best be derived by studying the last complex from of the metal that has the basic characteristics of the whole, that is, metal in the form of single crystals. In this way, many of the corrosion-influencing factors of polycrystalline materials can be isolated, and reproducible results can be obtained.

Single crystals are being used in research initiated at the Bureau in 1955 under the sponsorship of the Corrosion Research Council. Chosen to investigate the absorbed layers that form a metal surfaces was the metal-water-oxygen system. Copper was selected as the metal because it has a face-centered cubic structure, is readily available in high purity, and the corrosion products formed are few and simple.

Spherical specimens were initially employed in this work because they permit all of the crystallographic planes to be studied simultaneously. When carefully cleaned and polished specimens are exposed to water containing oxygen, different oxide interference colors appear on the various planes. Each color, readily identifiable from the patterns that are formed, indicates a different rate of growth of the corrosion products.

In one study, experiments were carried out both in open vessels exposed to the atmosphere, and in a closed all-glass apparatus in which the surrounding atmosphere and purity of the water were rigidly controlled. The differences in the composition and nature of the films that formed on similar specimens were attributed to the presence of carbon dioxide in the laboratory atmosphere

in the first experiment, and its absence under the controlled conditions of the second. During this study it was discovered that light has a marked inhibiting effect on the corrosion process.

Even the purest metals have many foreign atoms within their lattices. Less pure metals contain non-metallic inclusions, metallic impurities, and other inhomogeneities. Exposure to a corrosive medium of dissimilar metals in contact with each other, or of a metal with surface inhomogeneities causes galvanic (electrochemical) corrosion. Such corrosion can also occur on metal surfaces exposed to non-uniform electrolytes with variations in electrical conductivity, etc. The electrical current associated with corrosive action causes the metallic area with the more anodic solution potential to dissolve, forming a pit in the metal surface. The depth of pitting depends on the amount of current that flows from anode to cathode, which in turn may depend on several factors such as anode-to-cathode area, environment, temperature, and pressure. When the mechanism that causes the first pit to form can be determined, a great advance will have been made in understanding the corrosion process.

Galvanic corrosion which occurs on a continuous metallic surface cannot be measured directly. However, the Bureau has developed a method for evaluating this corrosion indirectly, on ferrous surfaces at least. In this method, the currents associated with the changes-in-slope in current-potential curves that occur during cathodic and anodic polarization are measured, and the values of applied polarizing current thus obtained are used to calculate the equivalent corrosion current. This indirect technique has been successfully applied in measuring the corrosion rates of steel in low-resistivity soils and in salt water. A variation of 1C per cent in corrosion rate can be detected in this way.

The crystal structure of metals has a direct bearing on stress-corrosion cracking, a particularly damaging type of failure resulting, as its name suggests, from the combined effects of stress and corrosion. Cracking may be either intercrystalline, as in aluminum alloys and low-carbon steels, or transcrystalline, as in magnesium alloys and stainless steels. Of particular interest are the cooper-zinc alloys, in which the attack is both ways.



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As a publication COMBUSTION has followed the education and the training of engineers entering its field of interest. This article discusses rather clearly the difficulties attendant to the application and advancement of engineering personnel

## The Discontented Engineer\*

By HILBERT SCHENCK, JR.

Clarkson College of Technology

THE discontent of engineers in America is a fairly well-known phenomenon among managers and personnel experts. Surveys even suggest that engineering employees may constitute the most dissatisfied group in industry. The turnover rate of from 10 per cent to 20 per cent a year and the formation of "Engineering Unions," which now claim to bargain for 12 per cent of employed engineers, indicate the need for analyzing reasons for this discontent.

Such a state of affairs is variously greeted by puzzlement, derision or dismay by engineering lay people. Viewing the excellent starting salaries of engineering graduates, the ever-increasing number of engineers in management positions, and the wide public interest in technical matters, some citizens are tempted to shrug off technical man's distress as the whimpering of a prima donna. Others, thinking of days long past, still visualize the engineer as a single-minded misfit who can get along with nobody. Actually, surveys of the engineer show that he is perhaps the most solid of citizens. He votes conservatively, his divorce rate is almost nil, he is not deeply in debt, and his devotion to his home and the education of his children is exemplary by any standard.

Writing in the March 1957 issue of the *Journal of Engineering Education*, Professor H. A. Shepard notes that surveys suggest that the vast majority of working

engineers want to become managers. Since only a relatively small proportion of any engineering group can achieve a responsible executive position, we might infer that discontent was the result of failure of the average engineer to achieve his goals. But such a simple explanation ignores certain other surveys and opinions. In *Electrical Engineering*, April 1957, for example, a survey of graduating seniors in electrical engineering shows that 62 per cent of a 3400 man sample selected development engineering as their working goal following employment, while only 13 per cent chose manufacturing or production. The authors note "Here again the strong technical bias of students is shown. They have great interest in work that contributes to new things and ideas and therefore to the advancement of science and art of engineering."

I would like to suggest that many engineers, perhaps the majority of them, have as a goal, a combination of the two apparently divergent aims just noted. The engineer wishes to work on primarily technical and specialized projects. Almost all of his background and his formal training have equipped him for such a career. Most engineers are poorly trained to supervise large groups of people, particularly when compared with certain business or liberal arts graduates. The situation is somewhat analogous to selecting a president of a drug company. We might wish to appoint a medical doctor to this position, but we must realistically admit that few doctors will have the proper training for such a job.

\* This article was published in the January-February 1959 edition of "The Clarkson Letter," and again in the May 1959 issue of the *Journal of the American Society of Naval Engineers, Inc.*

On the other hand, the engineer wishes to be treated as a management man. His difficult academic preparation, the insistent stress on his "professional" nature, and the wide publicity regarding his essential contributions to our well-being cannot help but instill in the engineer a feeling of self-importance, as well as realization of his unique capacities and talents. Since the majority of engineers function in an industrial situation, and since maximum status in this environment accrues to the manager, it is only natural that the engineer should aspire to management levels.

Unfortunately, the facts of economic and organizational life as now operative make it almost impossible for the engineer to reconcile this dual goal. As the engineer rises higher in the company hierarchy, he spends less and less time on the things that interest him most. A very few companies (General Electric is perhaps the best example) have attempted to create a double pathway to economic and status improvement. Those engineers equipped for personnel supervision, either by industrial training in college or by inclination, follow the traditional management ladder. Those not inclined in this way rise in salary and influence by purely technical excellence. How well this plan will work is difficult to say since it is a decidedly new concept.

In most industries, however, the young engineer remains as a relatively undifferentiated employee. By consulting "job descriptions" as set forth by his company, the young man sees that above a certain (and often very modest) salary level, over half his time will be spent on employee supervision, job rating, purchasing and procurement duties, sales and marketing conferences, and similar non-technical duties. The engineer covets the added income and substantial prestige and influences connected with such positions. He dreads the difficult problems, the dreary conferences, and the endless form-filling duties for which he is unprepared, both mentally and emotionally. The result, I submit, is frustration and discontent. Further, the engineer who is essentially technically oriented and never achieves high status is unlikely to fully develop his special abilities. On the other hand, his promotion to managerial status simply means that he has been displaced from the crucial creative phase of technology to a position that would better have been filled by a trained business-school graduate. Thus the company with no special rewards for talented technical ability does not effectively utilize the engineering employee in either role.

One problem lies in the failure of the engineering societies to properly differentiate the engineer from his industrial partners. For example, the American Society of Mechanical Engineers has sections devoted to the purest of technical investigation and sections devoted entirely to the practice of management in the mechanical industries. As a result, the society cannot speak or act in behalf of any homogeneous group. When

this problem is aired, some societies reply that the working engineer and the working manager share the same goals and ideals and thus can live beneath the same roof. This seems to be more wishful thinking than fact. The engineer who felt in tune with his non-engineering boss would not join a collective bargaining unit, yet more and more do so each year. Actually, the managing of a company whose products are engineering or are based on engineering is a specialized skill related to, but quite different from, the technical aspects of development and production. It would thus be entirely appropriate to break away from the major societies those sections devoted to management and form a separate group with this as its main object. The remaining members would then have a true technical society devoted wholly to the problems of the working engineer, and able to consider issues unique to this large group of skilled people. If a working engineer became a working manager, he would then simply change societies and thereby find a new group whose aims and views coincided more exactly with his own.

My belief is that the true engineering society should not engage in collective bargaining of any sort, for this is generally incompatible with creative endeavor. The true society should, on the other hand, carefully examine certain general problems and national issues as they relate to working engineers. The late lamented "engineering shortage" is an example of the lack of forthright leadership on the part of many of the societies. The president of one of the largest stated flatly (and with admirable accuracy) that a ten per cent decrease in gross national product would see "engineers coming out of our ears," but his was a voice in the wilderness. Most of the societies publicized the "needs" of the engineering profession and compared our own supply and Russia's. In view of the recent drop in engineering employment, one wonders if the employer members in the societies did not speak more loudly than the employee members. Discussions involving such issues as "engineers punching clock," the appropriate reward for discoveries by an employed engineer, and the addition of clerical help to relieve engineers of routine duties are difficult to carry on when both the person to be rewarded and the man who must pay for it are in the same organization. Yet it is in these very areas that the difficult and sensitive ideals of "professional attitude" and "professional development" are most often in doubt.

I believe that in the long run, the engineering executive who recognizes the dual requirements of status and the creative atmosphere in engineering jobs will not only obtain maximum utilization of his talent but will obtain it at little or no increase in cost. It is usually far cheaper to greatly reward the few individuals with honest talent, than to be continually forced into spiraling wage rises for every Tom, Dick and Harry with a degree and a sliderule.



## Abstracts From the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion Ltd., London, W.C. 1)

### Fuels: Sources, Properties and Preparation

**Coal Petrology and Coal Rank—Observations in Relation to Carbonization.** G. W. Fenton and A. H. V. Smith. *Gas World (Coking)* 1959, 54 (May 2), 81-7.

The objectives of coal petrology and the methods used for determining the petrographic constituents are reviewed. The application of coal petrology to improving the strength of coke by judicious blending of coals are discussed and the results of tests reproduced. Further work in this field is outlined.

**Microscopic Studies of Rate of Thermal Decomposition of Petrographic Components of Coal.** S. Ergun, H. J. O'Donnell and B. C. Parks. *Fuel* 1959, 38 (Apr.), 205-10.

Differences in the thermal behavior of exinites and vitrinites under conditions of slow rates of heating and instantaneous heating have been studied. The results are discussed.

**Chemical Structure and Properties of Coal XXII—Behaviour of Individual Macerals and Blends in the Audibert-Arnu Dilatometer.** D. W. van Krevelen, H. N. M. Dormans and F. J. Huntjens. *Fuel* 1959, 38 (Apr.), 165-82.

The percentage swelling of vitrinite and exinite concentrates and of blends of softening and non-softening coals has been studied. It is concluded that the thermal behavior of any coal or blend can be completely interpreted by means of maceral and rank analysis and the knowledge of the behavior of the individual macerals.

### Mechanical Handling

**Progress in Conveyor Belting.** L. Walter. *Gas World* 1959, 149 (Apr. 25), 784-90.

A review of recent developments, especially since the introduction of terylene giving greater strength and allowing wider and longer belts to be made is presented. Details are given of carrying capacity and abrasion resistance of various makes.

### Heat: Cycles and Transmission

**The Basic Heat Transfer and Flow Friction Characteristics of Six Compact High Performance Heat Transfer**

**Surfaces.** W. M. Kays. *A.S.M.E. Preprint No. 59-GTP-2* 1959 (Mar.), 8 pp.

The heat transfer characteristics and friction factors of four strip-fin type surfaces, one surface with perforated fin and one with wavy fins have been studied and the results are presented in tables and graphs. The surfaces are described sufficiently to enable heat exchanger design analyses to be made.

### Steam Generation and Power Production

**The Influence of the Inner Heat Transfer Coefficient  $\alpha_i$  on the Tube Wall Temperature of Superheaters.** P. Fröhlich. *Energie* 1959, 11 (Apr.), 149-53 (in German).

A diagram has been worked out on the basis of the latest Russian and American data for the calculation of the inner heat transfer coefficient. Its use for the calculation of the temperature difference between inner and outer wall at full and partial load and the siting of the final stage of the superheater in an actual boiler is illustrated. It is also shown that the diagram can be used to calculate the dependence of the most favorable steam velocity in the final superheater on pressure and temperature and the wall temperatures during starting to avoid overheating.

**Desuperheating Steam with Water.** S. S. Bowlus. *Power* 1959, 103 (May), 60-3.

An equation is developed for calculating the volume of water required to desuperheat a given volume of steam from a higher to a lower temperature at constant pressure. The design of direct contact desuperheaters is discussed and various types and their advantages, described. These include the carburetor, steam-assisted and variable-orifice type.

**Integrating Coal Properties with Boiler Design.** D. G. Hubert. *Combustion* 1959, 30 (Apr.), 38-45.

The effect of coal characteristics, especially ash content, sulfur content and grindability, on the design and performance of feeders, pulverizers, burners, furnaces, superheaters and reheaters, soot blowers, air heaters, fans and dust collectors are discussed.

**The Design, Installation and Use**

**of Packaged Steam Generators.** A. Wilson. *Steam Engr.* 1959, 28 (May), 255-66.

The various types of packaged boiler available in Great Britain, their sizes and working pressure, auxiliaries, combustion equipment, construction and installation, chimneys and water treatment are described. Makers' names and addresses are appended.

**New Packaged Boiler.** Anon. *Brit. Engng. Intern.* 1959, 41 (May), 325.

The Farrapac boiler is available in sizes from 4000 to 10,000 lb/h or  $4 \times 10^6$  to  $11 \times 10^6$  B.t.u./hr. It is of the triple-gas pass type and designed exclusively for oil or gas firing. The rotary cup burner can handle oil up to 3500 sec Redwood No. 1 at 100 F.

**The Operation of VTI Furnaces with High Slag Recovery.** Yu. L. Marshak and V. P. Romadin. *Elekt. Stantsii* 1959, 30 (Feb.), 2-8 (in Russian).

Operational experience and tests

(Continued on page 56)



**A. W. Hindenlang Joins Combustion Staff**

Beginning with this issue A. W. Hindenlang, formerly in the industrial division of Combustion Engineering, Inc., joins the staff of COMBUSTION. Mr. Hindenlang has authored a number of articles on industrial power and heating problems and addressed the ASME and ISA groups on the subject of boiler controls. He is a graduate of the University of Detroit as an aeronautical engineer and spent his early years with various aircraft manufacturers on controls and component design and stress analysis. Following service in the E.T.O. with the U. S. Army, Mr. Hindenlang accepted employment with Peabody Engineering Corporation, and gravitated toward the industrial power field with later service with the Pioneer Power Sales, Inc. and the industrial division of Combustion Engineering. Mr. Hindenlang is married, the father of three children, and makes his home in Freeport, Long Island.

indicate that combustion chambers using intensified slag entrapment practically eliminate the wear of heating surfaces, thanks to reduction in concentration and size of particles. This enables the permissible velocity of gases in the convective section of the boiler to be increased. Where 90 per cent of ash from particular fuels is recovered it is possible to dispense with the gas scrubbing necessary to comply with health regulations in regard to dust emissions.

From *C.E.G.B. Digest* 1959, 11 (May 23), 1232.

#### Solid Fuel Firing

**Experiences with Brown Coal Firing.** Anon. *Mitt. V.G.B.* No. 59 1959. (Apr.), 67-125 (in German).

A summary of a two-day Conference held in September 1957 is presented under the headings: 1. Fuel (analysis, grindability, slagging properties, difficulties and countermeasures); 2. Mills (types, throughput, control, wear, feed, developments); 3. Burners (jet and mixing); 4. Furnaces (burner arrangements, temperature distribution, slagging, siting of mills, flue gas turbulence, cooling, refractories, developments); 5. After-Combustion Installations (types, operational experiences); 6. Flue gas,

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pulverized coal and air ducts (cross-sections, fouling); 7. Convection heating surfaces (fouling, measures against fouling, corrosion, erosion); 8. Control (coal feed, air, flue gas).

#### Liquid and Gaseous Fuel Firing

**The Presidential Address 1959, "Oil Burners—1859 to 1959."** T. C. Bailey. *J. Inst. Fuel* 1959, 32 (May), 202-9.

**Oil Firing.** C. A. Landfermann. *BWK* 1959, 11 (Apr.), 175-6 (in German).

A brief review of the new German standards and papers published during 1958.

**Dimensionless Coefficients of Mixture Formation in Combustion Chambers. Pt. III.** W. H. Fritsch. *Energie* 1959, 11 (Apr.), 143-8 (in German).

The performance of an experimental burner operating with an oil pressure of up to 7000 psi, axially controlled air nozzles and a rotating, double-walled screen is discussed; the purpose of the screen is to remove all large oil droplets and thus to make the mixture more uniform. This results in a disklike instead of the usual cone-shaped flame and an almost uniform CO<sub>2</sub> content of the combustion gases over the combustion chamber cross-section. By a variation of oil pressure and axial movement of the burner nozzle a turndown ratio of 1:14 can be obtained.

**New Special Oil Burner for Industrial Heat.** G. J. Rickhey. *Tech. Mitt.* 1959, 52 (Apr.), 154-5 (in German).

Two types of burners are briefly described. The first operates with pressurized air at 0.05-2 atu; it can be provided with different heats to obtain either a flame of sharply limited shape or a widely divergent one. The burner output can be steplessly controlled from 10% of normal load to 20% above normal load. The second burner is a multiple-step-burner for the firing of several gases, and oil or pulverized coal singly or in any combination. Oil and coal are injected through the center tube which is surrounded by concentric tubes for air and gas (blast furnace, coke oven, town) in alternate tubes. Baffles at the outlet give the fuel and air a rotating movement to improve mixing. A burner of this type has been installed in a fire-tube boiler to replace coal firing. The boiler output was increased from 700,000 to 1,250,000 kcal/h, the thermal efficiency from 50-60 to 85-93 per cent and combustion was without smoke emission under all conditions.

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**The Oil Ash Corrosion Problem. An Application of the Phase Equilibrium Approach.** W. R. Foster. *Research* 1959, 12 (May), 189-95.

By means of compatibility triangles the corrosive compounds present in the solid and molten state of oil ash have been identified. It is shown that free  $V_2O_5$  is rarely present but that the compounds  $Na_2O \cdot 3V_2O_5$  and  $Na_2O \cdot V_2O_5 \cdot 5V_2O_5$  are of particular importance with regard to corrosion. It is believed that these findings will help research in further corrosion studies, especially the relative merits of various additives.

#### Furnaces and Combustion

**Theory of Flame Propagation.** Y. B. Zeldovich and G. I. Barenblatt. *Comb. and Flame* 1959, 3 (Mar.), 61-74.

A Russian study of previous work on flame propagation and a comparison of the various theories is presented. A numerical evaluation of the velocity of uniform propagation of flames has been carried out in which the effect of heat loss and chain reaction is considered. Equations for the steady state propagation of flames are developed and limits of validity indicated.

**Simplification of the Combustion Calculation for Fuels of High Water and Ash Content by a New Characterization of These Contents.** W. Gumz. *Glückauf* 1959, 95 (Apr. 11), 463-70 (in German).

For fuels of high ash and water contents it appears more useful to relate these to combustible substance and to state water, ash and mineral content as weight per weights of combustibles. This simplifies the calculation, and simple but exact equations for heat loss are obtained. The application of the new equations to brown and bituminous coals is demonstrated.

**Testing an Air-Cooled Slag-Tap Vertical Combustion Chamber.** L. A. Bogdanov and B. D. Katznelson. *Combustion* 1959, 30 (Apr.), 57-62.

A translation of a Russian paper on the design and operation of an air-cooled vertical cyclone chamber with gas outlet at the bottom.

#### Water-Side Corrosion and Water Treatment

**Treatment and Control of a Boiler Feed Water: New Interpretations.** E. C. Potter. *J. Inst. Fuel* 1959, 32 (May), 218-24.

The necessity for deaerating feed-water and making it alkaline are discussed and answered positively. It is further argued that measurement of



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pH should be replaced by that of pOH because this value is less dependent on temperature. The practice of measuring the hydrogen content as a measure of internal corrosion is considered unconvincing. It is also felt that the British practice of over dimensioning tube wall thicknesses may lead to stress corrosion and there is both a maximum and a minimum safe tube wall thickness.

**Feed Water Treatment.** E. Schumann. *BWK* 1959, 11 (Apr.), 179-80 (in German).

A brief review of the new specifications published in 1958, complete demineralization, acid cleaning of boilers and cleaning of condensers.

**Oxygen and Carbon Dioxide Corrosion.** P. Brindisi. *Combustion* 1959, 30 (Apr.), 47-52.

The amounts of dissolved oxygen and CO<sub>2</sub> in water and their corrosive attacks are considered and the reactions these gases undergo with various substances added to reduce or eliminate them from water and steam are discussed.

#### Gas-Side Corrosion and Deposits

**The Variation with Temperature of the Catalytic Activity of an Oxidized Stainless Steel Surface in the Oxidation of Sulfur Dioxide.** R. S. Fielder, P. J. Jackson and E. Raask. *Fuel* 1959, 38 (Apr.), 257-8.

In preliminary experiments on the question of the possible catalytic activity of oxidized steel superheater surfaces in the oxidation of SO<sub>2</sub> to SO<sub>3</sub> it was found that above 570 C (1058 F) the percentage oxidation increased steeply. This is possibly due to a change in the nature of the oxide layer on steel. Further work to clarify this and other points is in progress.

**A Theoretical Analysis of Thermal Surface Fouling.** D. Q. Kern and R. E. Seaton. *Brit. Chem. Engng.* 1959, 4 (May), 258-62.

The physical and mathematical relationships between allowable pressure drop and the accumulation of dirt with time are presented and illustrated by numerical examples.

#### Flue Gas, Ash and Dust

**Ash and Slag.** W. Gumz. *BWK* 1959, 11 (Apr.), 178-9 (in German).

A review of recent papers on ash and slag studies and their utilization.

**Flue Gas Dedusting.** P. Noss. *BWK* 1959, 11 (Apr.), 176-8 (in German).

Developments of improved electrodes for electrostatic precipitators, of wet scrubbers for fumes from converters and of combined scrubber and



precipitator plants are reviewed.

**Selective Particle Acceleration.** New Dust Collector Features "Unique Principle." Anon. *Gas J.* 1959, 298 (Apr. 29), 212.

A centrifugal type dust collector is described in which the gas is accelerated toward the operating zone to six times its entry velocity by the helical guide vanes and the rapidly diminishing entry section. The cleaned gas emerges through the inner outlet tube at the inlet end and the concentrated dust at the other end. It is claimed that 80 per cent of particles of  $5\ \mu$  size and 93 per cent of particles of  $10\ \mu$  size are collected.

#### Heat Recovery Plant

**A Simplified Regenerator Theory.** W. F. Schalkwijk. *J. Engng. for Pwr.* 1959, 81 (Apr.), 142-50.

Equations for calculating the efficiency of regenerators have been developed for the symmetrical case in which the parameters have the same values in both directions of gas flow, and also for the general case.

**Systematic Studies of Heat Transfer and Flow Resistance of Finned Tubes, a Contribution to the Use of Special Tubes in Gas-Cooled Reactors.** G. Grass and F. P. Coenen. *Atomkernenergie* 1959, 4 (Feb.), 41-8 (in German).

The influence of fin height and distance and Re number on heat transfer and pressure drop has been studied and the results are presented in graphs. These should make it possible to arrive at optimum dimensions.

#### Power Generation And Power Plant

**Brown Coal Firing.** H. Lenkewitz. *BWK* 1959, 11 (Apr.), 173-5 (in German).

Developments in mill, burner, dry and slagging furnaces and electrostatic precipitators, for brown coal boilers.

**Application of Supercritical Steam Parameters at Thermal Power Plants.** K. A. Rakov. *Teploenergetika* 1959, (May), 22-8 (in Russian).

The possibility of reconstructing existing power plants for operation at supercritical steam parameters and the re-equipment of medium pressure plants to those with supercritical steam parameters are considered.

**The Garigliano Nuclear Power Station.** Anon. *Nucl. Engng.* 1959, 4 (May), 220-3.

The 150 MW boiling water reactor by International General Electric Co. for erection in Italy is described. Details include the pressure vessel, core and fuel elements, turbogenerator and safety provisions.



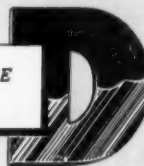
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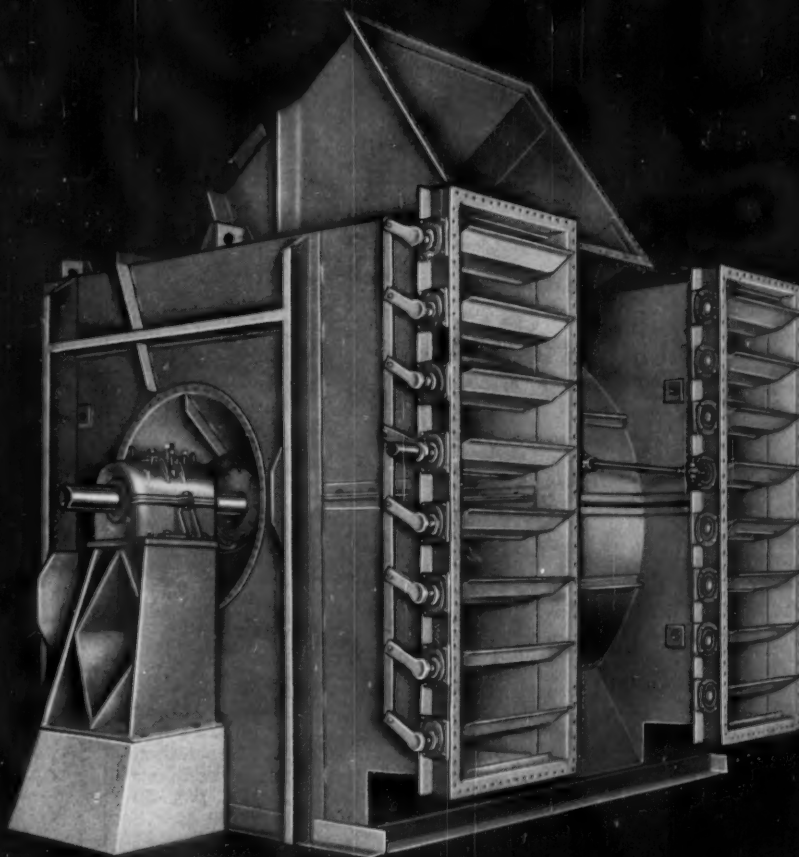
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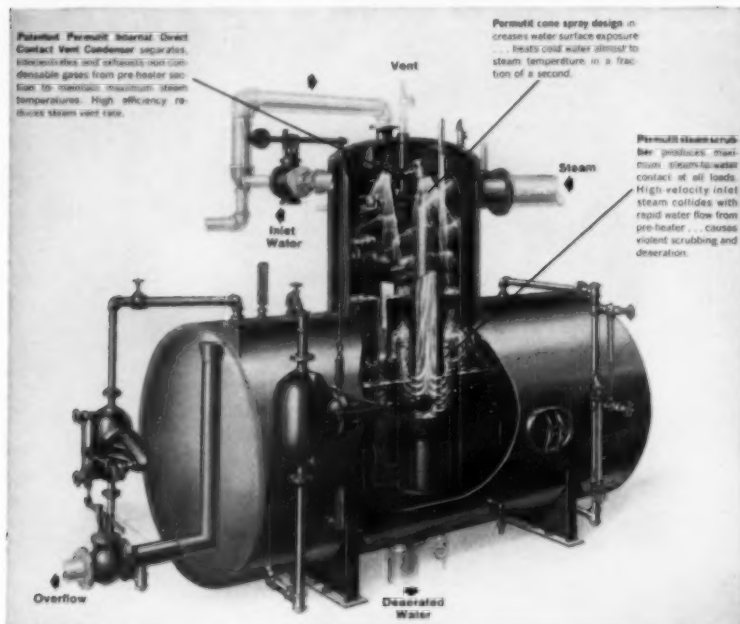
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agitation	storing

Whenever you have a fluid-handling problem, look to this Pfaudler Permutit FLUIDICS program for the best solution.

Specialists in FLUIDICS... the science of fluid processes

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*Largest Merchant Iron Producer in U. S. Chooses*

## WHIRLEX ID FANS

**High Erosion Resistant  
Fan Wheel Assures  
Longer Life ...  
Minimum Maintenance**

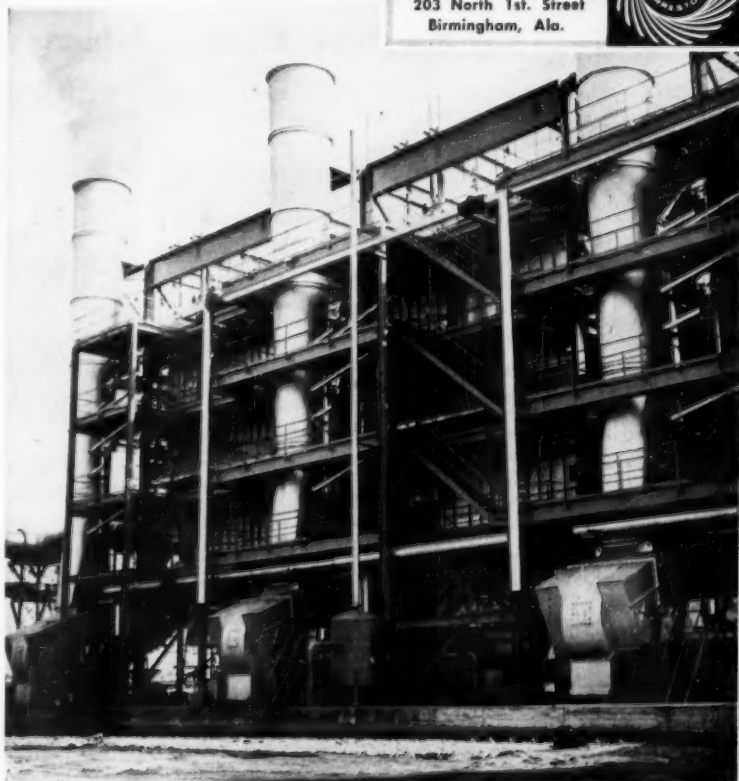
The largest furnace in the country producing merchant pig iron was recently placed in service as part of an expansion program by a major Southern mill. The new furnace has a rated capacity of 1000 tons per day and is one of the most modern in the country with respect to mechanization and automatic controls.

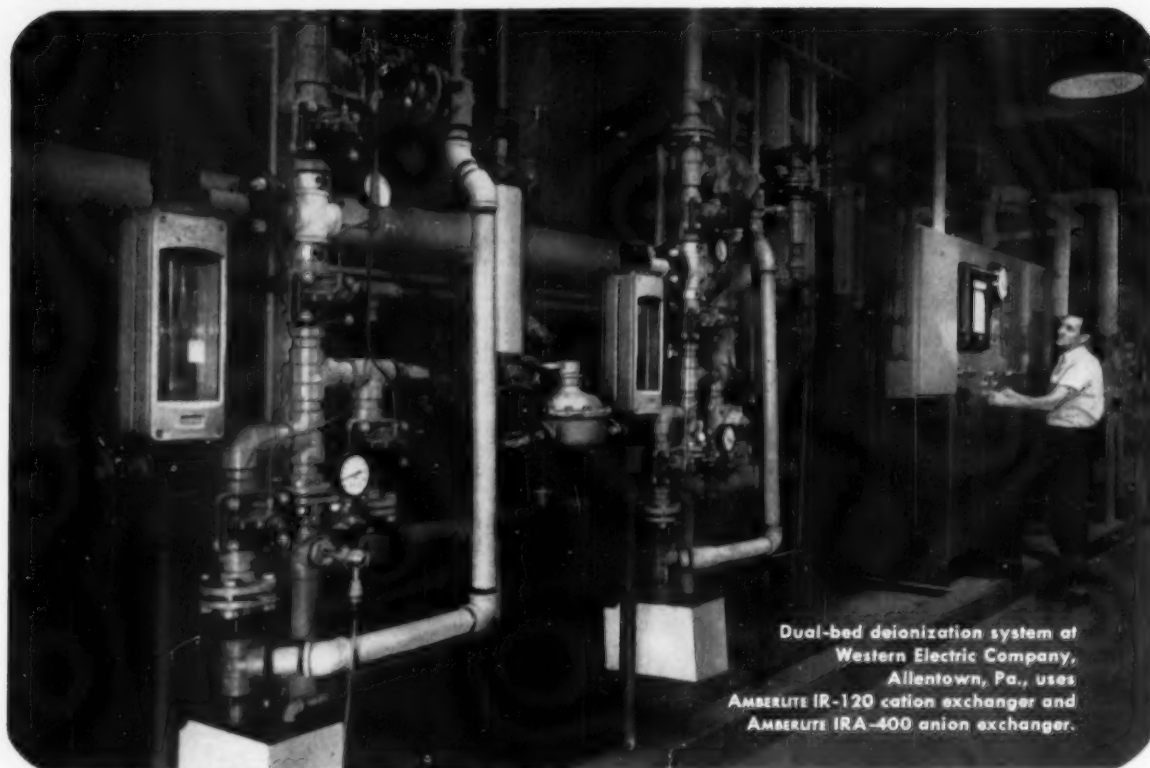
Because of their unique

design and high erosive resistance, WHIRLEX heavy duty induced draft fans were chosen to handle the hot blast furnace gas. The three units shown here carry approximately 150,000 cubic feet of gas per minute. Preliminary fan examinations show wear to be less than a third that of ordinary fans designed for this purpose.

*A Whirlex fan installation  
may solve your problem.  
Write or wire us.*

**Fly Ash  
Arrestor Corp.**  
203 North 1st. Street  
Birmingham, Ala.





Dual-bed deionization system at Western Electric Company, Allentown, Pa., uses AMBERLITE IR-120 cation exchanger and AMBERLITE IRA-400 anion exchanger.

## **AMBERLITE-deionized water meets critical specifications at Western Electric Allentown Works**

It would take 28 successive distillations in quartz to equal results being delivered by ion exchange at the Allentown, Pa., Works of Western Electric.

Deionized water is used in the preparation of acid and chemical solutions and for washing and cascade rinsing during the manufacture of electron tubes, transistors and semi-conductors. The presence of even minute quantities of metal impurities could seriously affect the performance of these critical electronic parts.

Two grades of deionized water are provided; water from the Allentown City System passes through a bed of AMBERLITE IR-120, cation exchange resin, and then through AMBERLITE IRA-400, anion exchanger, to provide water for most requirements of the plant. Conductivity of the water is reduced in one pass from 250 to 300 micromhos to less than 2.5. This semi-automatic unit has a capacity of 120,000 gallons between regenerations. The treated water is delivered to work stations under a constant head by a recirculating stainless steel grid.

Where water of minimum conductivity is needed, MONOBED units containing a mixture of AMBERLITE IR-120 and IRA-410 are used to polish this deionized water, providing a 40-gallon per hour flow of water with a conductivity of 0.2 micromho or less. These 4-inch diameter cartridge units are removed upon exhaustion for regeneration at a central location in the plant.

Consult your engineering company experienced in water conditioning on how AMBERLITE ion exchange resins may help you. Write for a copy of our booklet "If You Use Water".



MONOBED deionizers containing a mixture of AMBERLITE IR-120 and IRA-410 provide water with a conductivity of less than 0.2 micromho.

AMBERLITE and MONOBED are trademarks Reg. U.S. Pat. Off. and in principal foreign countries.



*Chemicals for Industry*

**ROHM & HAAS  
COMPANY**

THE RESINOUS PRODUCTS DIVISION  
Washington Square, Philadelphia 5, Pa.

MORE THAN ~~950 1400~~ **2500**

## DIAMOND MULTI-PORT GAUGES

In use and on order  
for over ~~240~~ ~~300~~ **325**  
Central Station  
Generating Plants

MODEL MP-3000 SHOWN

For boiler pressures to 3000 psig  
For both new and old boilers



Because the Diamond Multi-Port solves the problems inherent in water level gauges on boilers operating at high temperatures and pressures, and has made startling reductions in maintenance costs, it has had rapid and wide acceptance. In addition to the 2500 for central station generating

plants, more than 200 have been sold to industrial power plants.

Advantages of the Multi-Port are many. In addition to those shown above, it has maximum thermal stability for rapid starting . . . "Hi-Lite" illuminator for improved readability . . . welded construction for permanent tightness . . . end stems can be furnished instead of flanges.

Write for Bulletin 1174 (Model MP-3000) or Bulletin 2044 (Model MP-1050) for more information.

*Diamond*

**DIAMOND POWER SPECIALTY CORP.**

LANCASTER, OHIO • DIAMOND SPECIALTY LIMITED — Windsor, Ontario

NEW IDEAS IN CHEMICAL CLEANING



## New Jetting Tool To Clean Tube Bundles Saves Thousands Of Dollars

The new high-pressure hydraulic tool, shown above, is currently saving thousands of dollars for companies in the refining, chemical, and petrochemical industries. It is the jetting tool developed by Dowell to remove deposits from heat exchanger tube bundles.

Previous methods of cleaning these bundles have been costly, time-consuming and often inadequate. Many times bundles had to be replaced completely because of the lack of a suitable cleaning method.

This new Dowell tool has a remarkable record of thorough, fast cleaning. For example, a slurry reboiler exchanger bundle, three feet in diameter and 16 feet long, was fouled with deposits of coke and asphalt. After being jetted from only one side, the bundle was

thoroughly clean. Time required: less than one hour.

The tool holds the bundle in place for cleaning and has flanged rollers for rotation. The jet-head is manipulated automatically so that all tube spaces are covered. The jetted liquid can be either water or chemical solvents.

This high-velocity jetting device is another example of the new ideas Dowell continues to offer in chemical cleaning to help you cut your costs. Whatever the cleaning problem in your plant, call Dowell for an engineered recommendation. Dowell—the largest, the oldest, the most experienced chemical cleaning service—Tulsa 1, Oklahoma; and 165 stations and offices in major industrial centers.

*Chemical cleaning service for all industry*

DIVISION OF THE DOW CHEMICAL COMPANY

**DOWELL**



